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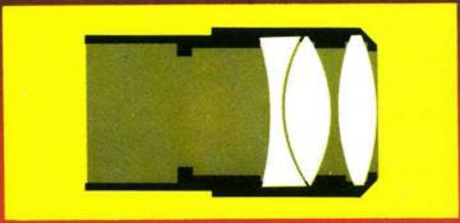

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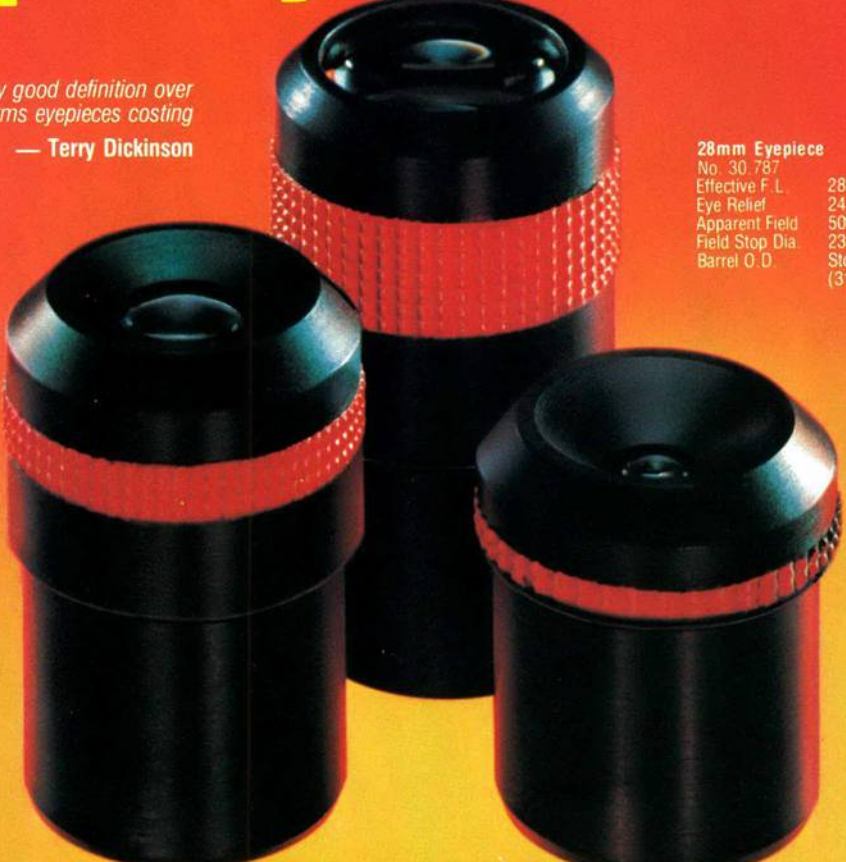

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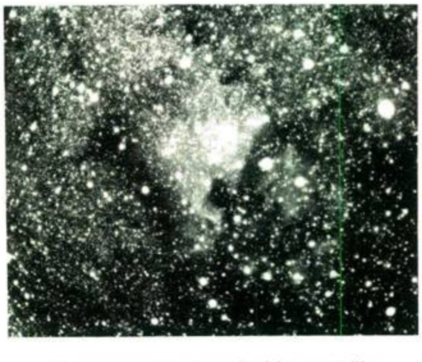

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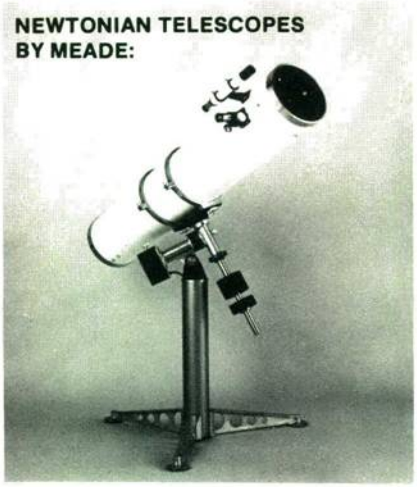

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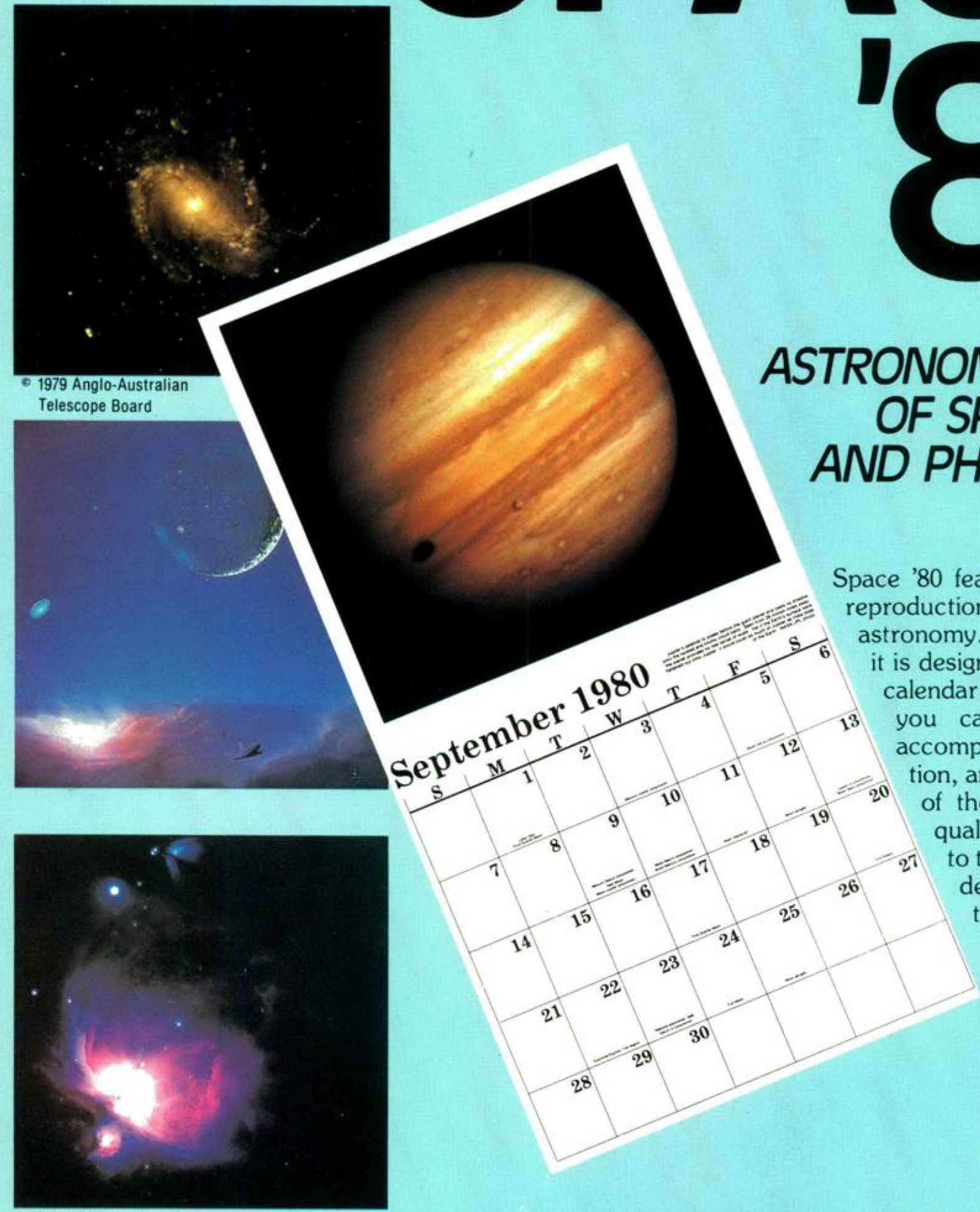

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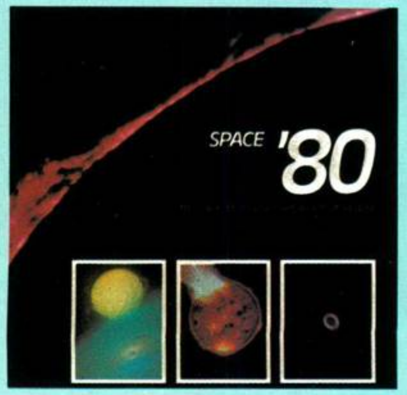

ASTRONOMY

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Cover: From the naked-eye familiarity of Earth's own satellite in eclipse, ASTRONOMY this month takes you to the bizarre realm of the quasars — incredibly distant starlike objects spewing energy into the cosmos. The quasars appear, however, to be related to other, more comprehensible galaxies nearby, perhaps providing a vital clue to their nature. Do you want to see a quasar? — then turn to Gazer's Gazette. On the cover, Jerry McKenzie's fine photograph of September 6th's predawn total lunar eclipse.

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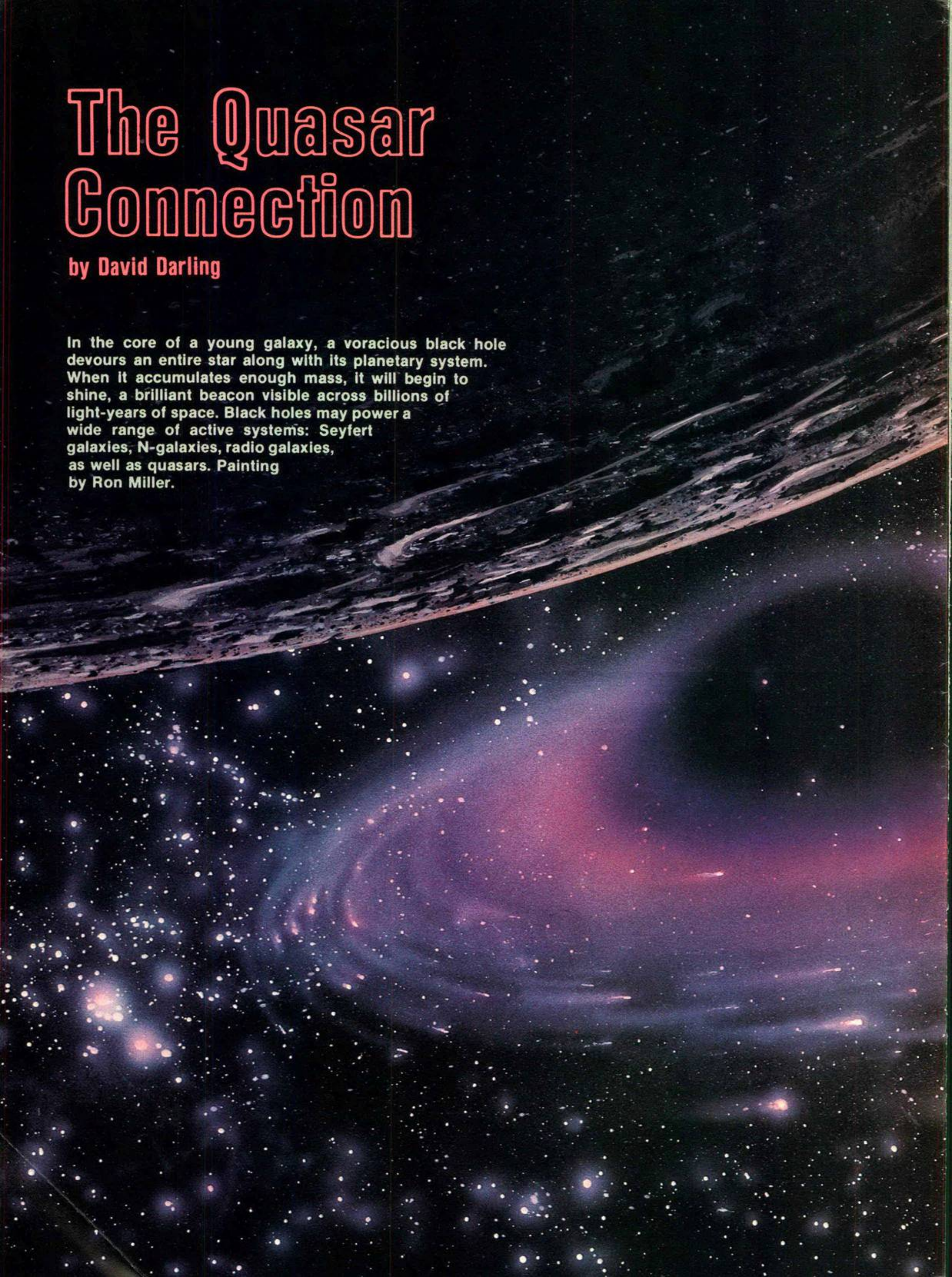
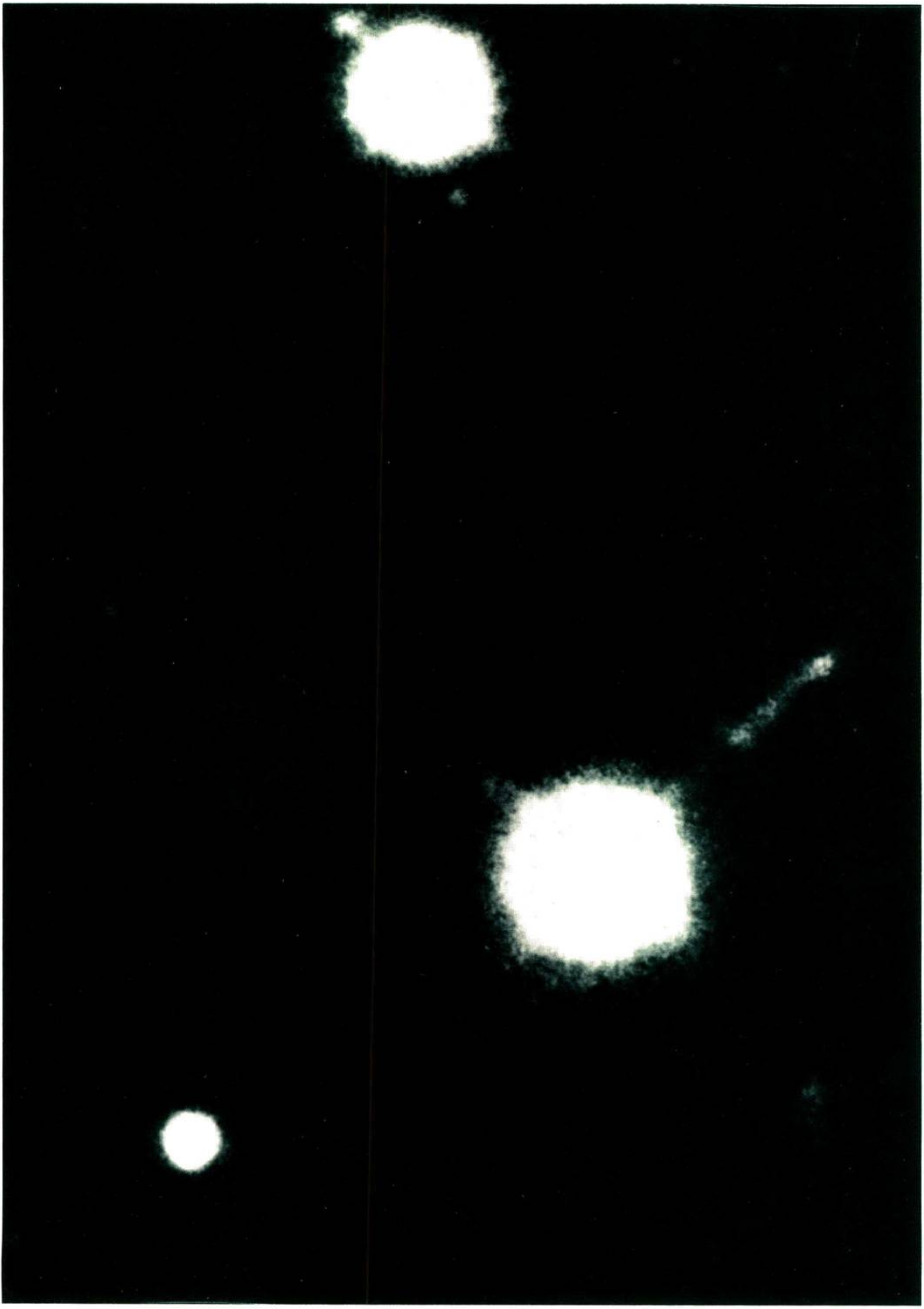
The Quasar Connection

by David Darling



In the core of a young galaxy, a voracious black hole devours an entire star along with its planetary system. When it accumulates enough mass, it will begin to shine, a brilliant beacon visible across billions of light-years of space. Black holes may power a wide range of active systems: Seyfert galaxies, N-galaxies, radio galaxies, as well as quasars. Painting by Ron Miller.



Out at the edge of the universe lie objects whose colossal energy output astounds us. Through radio eyes, we glimpse vast single structures as large as whole clusters of galaxies. And throughout space, we're becoming aware of a bewildering assortment of new stellar communities — from the bright-eyed Seyfert galaxies to the delicate cartwheels of ring galaxies. These are the newly-found members of the galactic family: distant (and maybe not so distant) relatives of systems like our own Milky Way.

The last twenty years have seen our ideas on the structure and evolution of galaxies turned upside down. The time is ripe for a new classification, and astronomers are rising to the challenge.

What powerhouse drives a quasar? Is there really a massive black hole at the heart of M-87? Why does M-82 seem to be blowing up? And what in the world — or rather the universe — is an N-galaxy?

Tantalizing questions like these abound in the fast-growing field of extragalactic astronomy. And they're directly linked to a fascinating new concept. Galaxies can be *active*. Entire galaxies, like individual stars, can go through rapid phases of evolution involving huge outpourings of energy.

Violent events in stars tend to occur in the late stages of stellar evolution. Supernovae, for instance, are the shattering final explosions of massive stars which have totally exhausted their nuclear energy reserves. Is the same true of whole galaxies? Are these newly-discovered super-energetic galaxies suffering from advanced old age?

On the contrary, it seems more and more true that galaxies tend to be especially active in their youth. So-called "normal" galaxies — the elder statesmen of galactic society — may well have passed through earlier, more compact states in reaching their present stable conditions.

Exactly what determines if a galaxy is "normal" or "active"? The answer is simple. The key factor is the length of time over which that galaxy can sustain its present total energy output.

Normal galaxies are conservative in their energy use. There's no reason why a healthy system like the Great Nebula in Andromeda (M-31), discarding energy at a modest rate, shouldn't maintain its present output for many more billions of years. The same applies to the majority of galaxies in the observable universe.

Active galaxies, on the other hand, throw out energy recklessly. Often they're rocked by large-scale internal explosions. Extremely rapid variability, both in the radio and optical spectra, is another common feature. One fact stands out very clearly. There's no way that active galaxies can keep up their observed level of energy output for any significant length of time. Compared with the total lifetime of a galaxy, energetic galactic activity must be very short-lived.

The quasar 3C 273, shown opposite, was the first of thousands of such objects to be identified. While most quasars appear star-like under all circumstances (hence the name, "quasi-stellar" = quasar), a few show some evidence of structure. 3C 273 exhibits a distinctive optical jet, which has been identified as the source of its radio emission. Compare this feature with the similar one observed in the photograph of the giant elliptical galaxy M-87 on page 12. Photograph courtesy of Kitt Peak National Observatory.

A normal galaxy, such as the spiral galaxy NGC-6744 shown above, appears very different from a quasar. Yet astronomers are beginning to suspect that some complex evolutionary process in fact links these two cosmic species. It may be that in the distant and ancient quasars we see the infancy of mature galaxies such as this one. Photo by Cerro Tololo Inter-American Observatory.

Is our own galaxy active? Are any of the nearby galactic systems active? Let's take a look around our neighboring space and find out.

Within 2 or 3 million light-years of the Milky Way is a collection of about 30 individual galaxies making up what is called the Local Group. We're privileged to be aboard one of its dominant systems — a majestic spiral galaxy containing over 100 billion stars. Even more impressive is the Andromeda spiral, two million light-years distant and weighing in with over twice as many stars as the Milky Way. And like pilot fish around a shark, each of these giant spirals is attended by a number of very much smaller elliptical and irregular systems trapped by their mighty gravitational fields.

Do we see any signs of violent activity within the Local Group? The answer is no — with just one possible exception.

At the center of our own galaxy, 30,000 light-years away in the direction of Sagittarius, a number of very odd things are going on. First, an explosion seems to have taken place there in the relatively recent past. Several million solar-masses worth of hot gas is now rushing outwards at high speed, signaling its presence by strong emission at radio and infrared wavelengths. Second, the center itself is inhabited by several peculiar radio and infrared sources. Just what the driving force behind all this activity might be is unclear. One imaginative suggestion is that a star-gobbling black hole might lurk at the core of the galaxy, the engine room for high-energy phenomena there.

The Milky Way certainly isn't the placid place that we, as dwellers in the periphery, might suppose. Behind the veil of thousands of light-years of dense interstellar gas and dust is hidden a small core where violent events are commonplace. "Things that go bump" in the core, though, may be just dying echoes of an earlier phase of true galaxy-wide activity.

Leaving behind the quiet backwater of the Local Group, let's set out on a cosmic safari. What kinds of strange galactic "creatures" await us in the universe at large? How are they related? And just what fantastic mechanisms drive their powerful hearts?

10 million light-years away, in the direction of Ursa Major, we find our first prize specimen: the galaxy M-82. At first sight, we could be excused for questioning whether this bizarre object is even a true galaxy. Vast billowing clouds of gas and dust make up the whole of its long elliptical face. Not a single star shows clearly through the swirling maelstrom.

No longer does space seem calm and orderly. We've glimpsed scenes of unimaginable violence both within our galaxy and beyond: matter-crushing gravity pits, galaxy-tearing tidal forces, and super-galaxies with a hundred times the energy output of the Milky Way. Out toward the very edge of the observable universe, lie the brightest and most energetic systems of all — the infamous quasars.

In the red light of hydrogen, M-82 reveals more of its secrets. Streaming out of the nucleus, in all directions, are long, mottled filaments. Is this the debris from a galaxy-wide explosion? Is M-82 blowing up?

Until very recently, most astronomers would probably have supported the idea of a major eruption in M-82. Proponents of the explosion model suggest that in the polar regions of the galaxy, gas has been ejected with speeds of over 1000 km per second — sure signs of a major blowout in the core.

The new model of M-82 has a different explanation for the observed velocity structure of gas in the galaxy. It's a model which comes as something of a disappointment for hunters of genuinely "active" systems. The concept of a super-scale explosion is replaced by one of fast and widespread star formation. Far from blowing itself to bits, M-82 might be in the process of a spectacular rejuvenation.

Where's the support for this idea of major star formation? It comes from the observation at radio wavelengths of a vast but tenuous hydrogen cloud which totally cocoons both M-82 and its much larger neighbor M-81. Material from this cloud drifting past M-82 is occasionally sucked into the very heart of the galaxy. This is what seems to have happened in the fairly recent past.

As portions of the intergalactic cloud were drawn into M-82, they greatly increased in density. The end result? Regions of the galaxy where star formation had already been taking place, were compressed even further by the arrival of this new material. The rate of star formation stepped up dramatically.

Today, astronomers may be seeing the spectacular outcome of multiple star births in M-82. Hot dust in the stellar birthing places and supernovae remnants at the sites of massive stars that raced through their life cycles would be just right to account for the copious infrared and radio signals which we receive.

So it seems we've been cheated. M-82 continues to fascinate us and the space it inhabits turns out to be a complex region of tidally-interacting systems. But still we're left with a pretty normal, small spiral galaxy with nothing too unusual about the way it makes its energy. Our closest potentially "active" object isn't really active at all.

Let's go hunting further afield. Rumor has it that something big and mysterious lurks within the Virgo cluster....

65 million light-years away it lies: a monster galaxy, 100 times as massive as our own. Yet the sheer size and luminosity of the giant elliptical M-87 aren't its only claims to distinction. A number of singular features mark out this galaxy from the crowd.

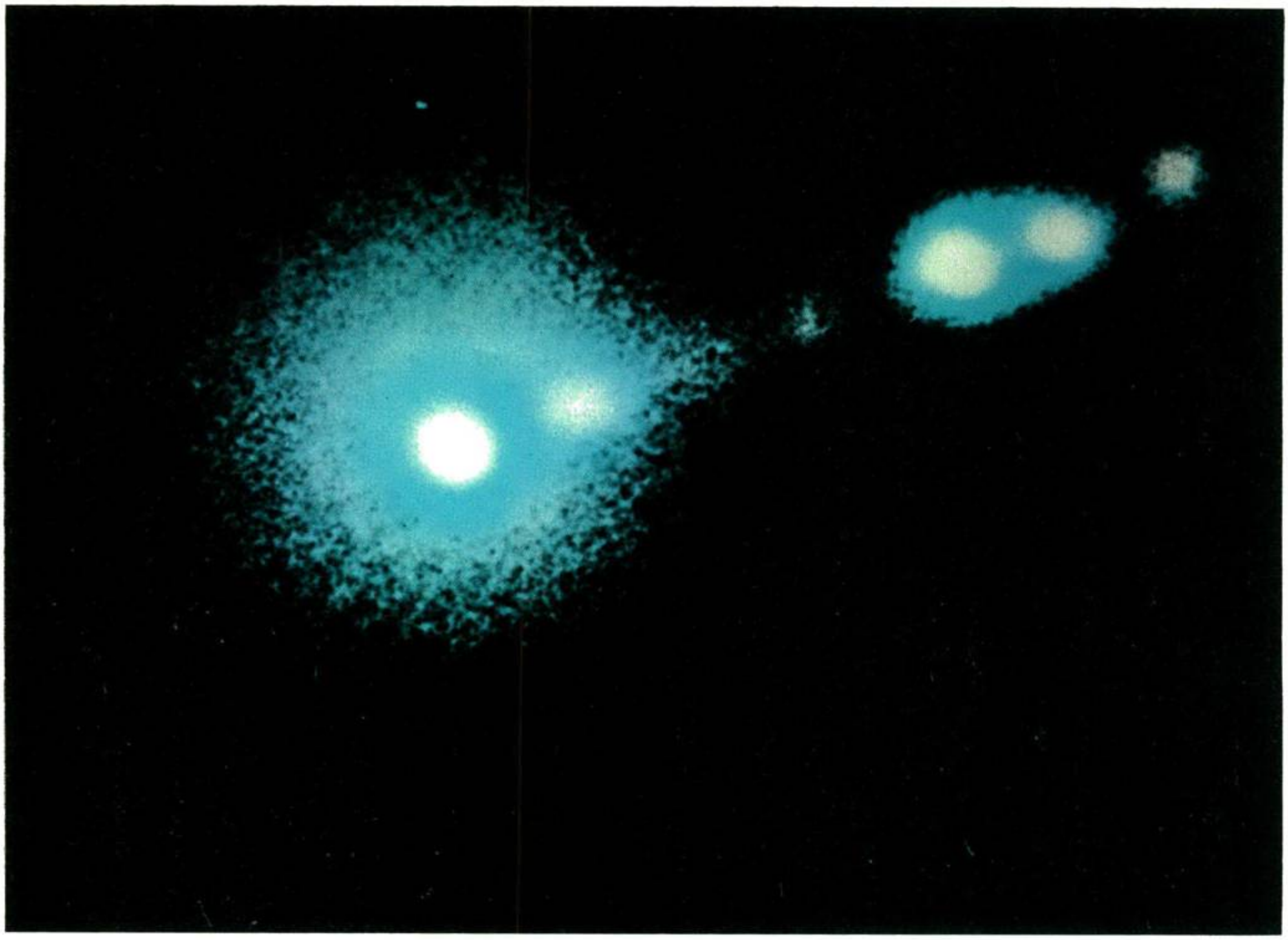
What, for instance, could have thrown out the long jet-like feature we see projecting from its side? The same power center, perhaps, that constitutes an intense X-ray source at the core?

All the current indications are that something really unusual is going on within the nucleus of M-87. Here, astronomers think, is the site of true galactic activity — one of the very nearest specimens of such activity to the Milky Way.

M-87 is a favorite target for observers working at virtually all wavelengths — radio, optical, and X-ray. Its famous, 7000 light-year-long jet burns bright in the radio region: kindled by the emission from electrons racing at near light-speed in a weak magnetic field. X-rays pour from its troubled core — the first clues to the existence of a strange beast which hides there.

But of all the recent observations of M-87, perhaps the most exciting are some of those made in the more familiar, visible region of the spectrum. The essence of what they tell us is simple. The mass

Some galaxies, such as the peculiar M-82 shown opposite, seem to be undergoing some sort of violent upheaval in their central regions. This particular galaxy, far closer to us than the nearest quasars, actually seems to be exploding. Whether this violent occurance is in some way related to the highly energetic processes powering quasars and the even more active Seyfert and N-type galaxies is one of the great mysteries of modern astronomy. Cerro Tololo Inter-American Observatory photograph.



The above photograph of the peculiar jet emanating from the center of the giant elliptical galaxy M-87 has been computer-processed and specially printed to show structural detail within the jet. Seven luminous condensations, perhaps the result of huge pulsed explosions, are clearly visible. Photographs courtesy of Hale Observatories.

of the central nucleus of M-87 is far too great to be accounted for by the total mass of the stars which we know to be there. To be exact, there seems to be around 60 solar masses of dark matter for every single solar mass which contributes to the central luminosity. Stars crowd close together in the core of this strange galaxy — prisoners of an invisible object with 5 billion times the mass of our Sun. Could this unseen object — with a diameter of no more than a few hundred light-years — be a supermassive black hole? Many astronomers today would answer "yes."

A big black hole at the center of M-87 may be a fascinating concept, but what has it to do with our discussion? Just this: theorists have been suggesting for several years that very dense objects could go a long way towards explaining the unusual behavior of active galaxies. In particular, the neighborhood of a massive black hole is an especially rich source of high-energy phenomena. Galaxy-wide activity may be the signature of supermassive black holes.

Later on, we'll be looking in turn at each of the major classes of active galaxies. We'll encounter the quasars, the Seyferts, the huge radio galaxies, and others. Could these systems, too, ultimately be powered by heavyweight black holes at their cores?

The chain of logic isn't immediately obvious. On the one hand, we're told that not even light can escape from the surface of a black hole. On the other, we're asked to believe that they can transform an otherwise normal system of stars into a galactic blockbuster, a brilliant cosmic beacon. Isn't there a contradiction here? No! It's perfectly true that nothing — not even light, the ultimate escape artist — can break out from the interior of a black hole. The energy source which may power active galaxies isn't the black hole itself, but the *accretion disk* which surrounds it.

Now we ask: What's an accretion disk?

Imagine the fantastic conditions we might find at the core of an active system like M-87. Dominating the very center is a supergiant black hole — a bottomless pit in space. Towards its edges, the stars of the core are drawn like moths to a bright light. The black hole's gravitational field, pulling with the combined might of 5 billion suns, is an inescapable trap for matter straying too close to the galaxy's heart.

As stars hover in the twilight zone close to the black hole's surface, they're gradually stripped of their loose-fitting outer envelopes. The black hole

The Active Galaxy Energy League

In this table we're making a comparison between the energy output of active galaxies at various wavelengths and that of a typical normal spiral at the same wavelengths. The figures don't reflect the relative importance of energy output in the different spectral regions. Normal spirals, for instance, give off vastly more energy at optical wavelengths than they do in the radio region. N-galaxies and quasars, on the other hand, are especially active in the infrared, and by comparison their optical emission is insignificant.

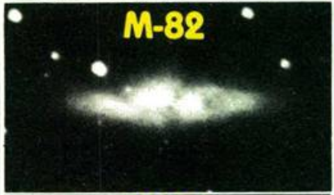
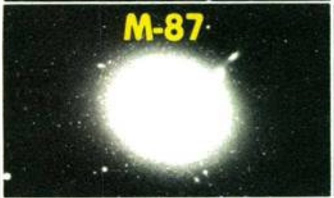
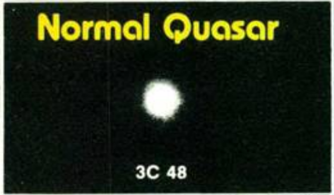
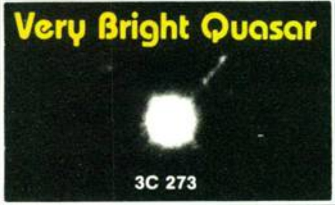
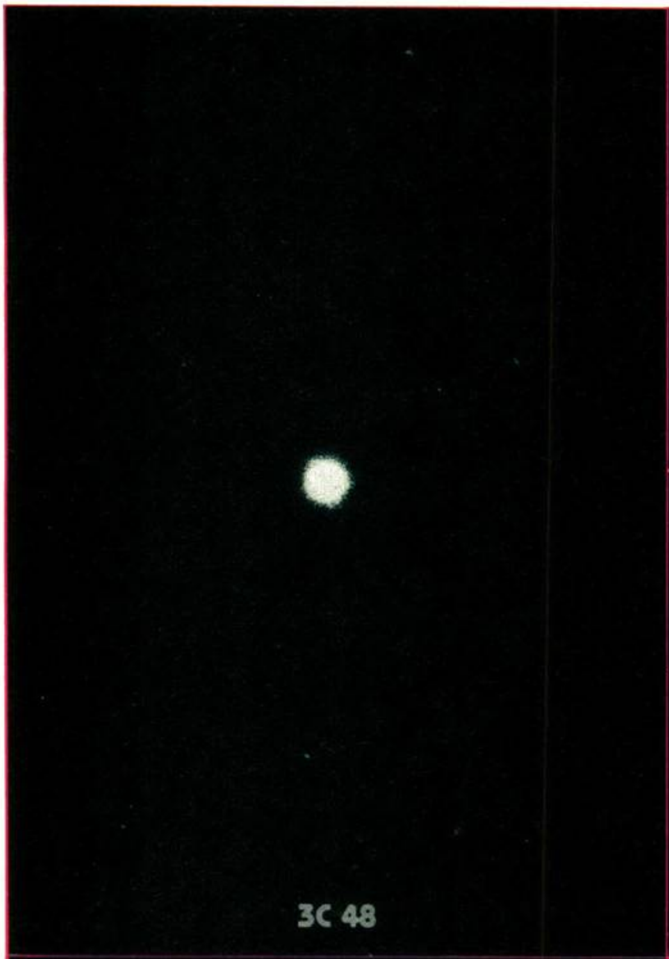
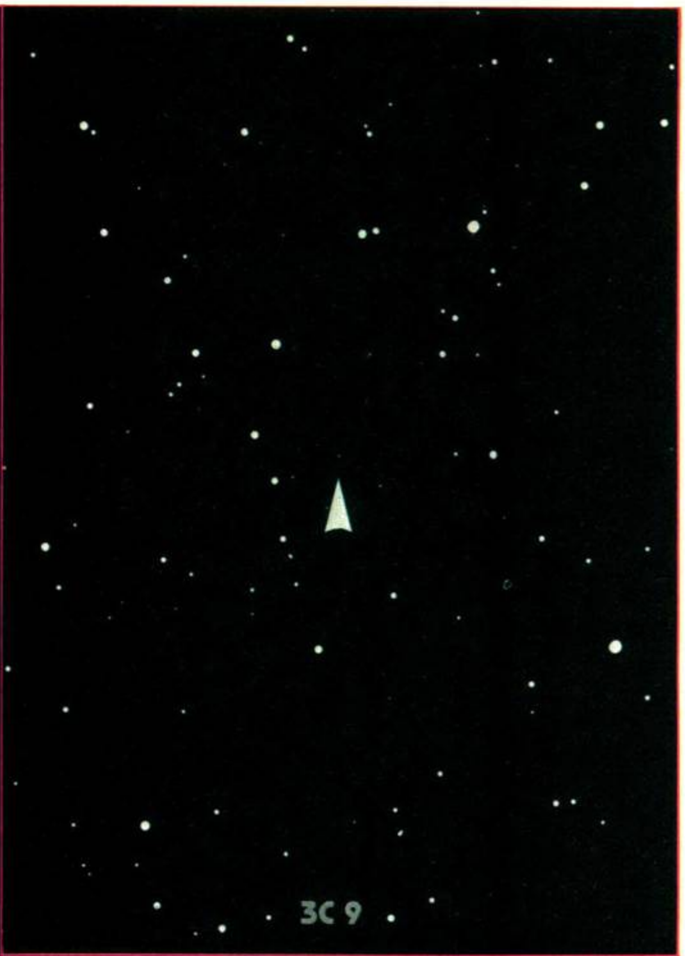
	Radio	Infrared	Optical	X-ray
Normal Spiral NGC-6946	1	1	1	1
M-82 	6	70	?	?
M-87 	1,800	1.5	2.5	5,000
Radio Galaxy NGC-1275	2,000 - 2,000,000	0.5 - 1.5	2.5	100 - 5,000
N-Galaxy/Seyfert NGC-4151	20 - 2,000,000	10,000	1.5	300 - 70,000
Normal Quasar  3C 48	200,000 - 2,000,000	300 - 50,000	?	?
Very Bright Quasar  3C 273	6,000,000	300,000	250	2,500,000

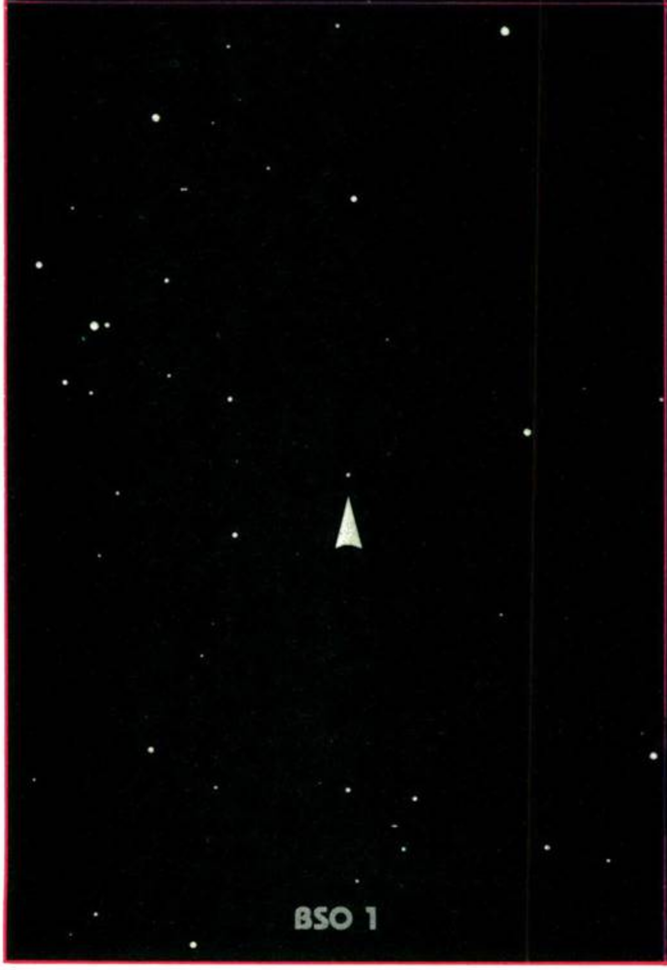
Photo credits: Kitt Peak National Observatory: NGC-6946, M-87, NGC-127. Hale Observatories: M-82, NGC-4151, 3C 48, 3C 273.



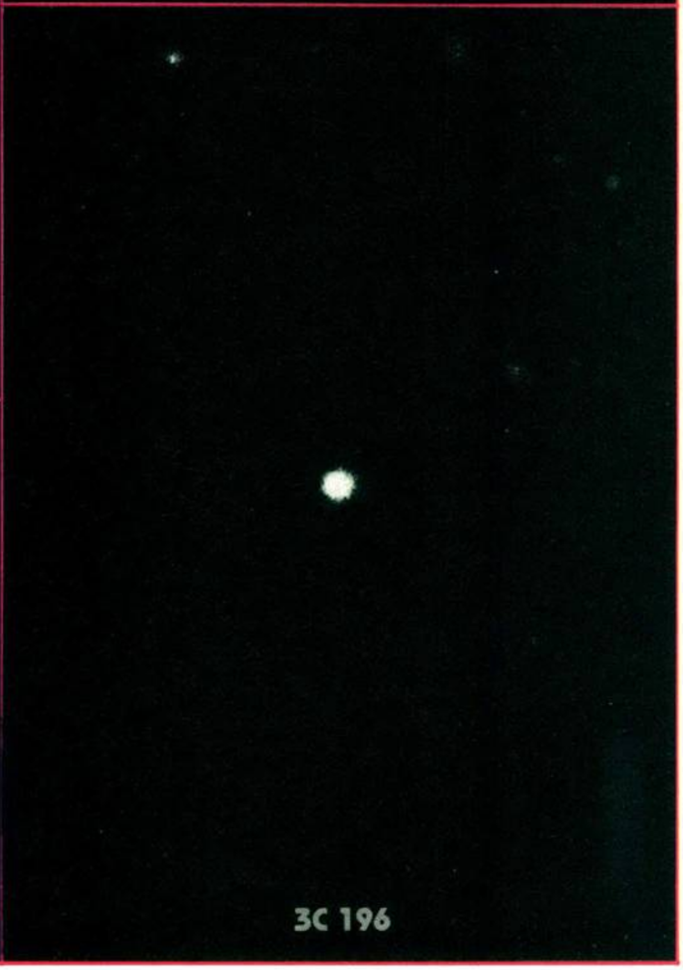
3C 48



3C 9



BSO 1



3C 196

exacts high stellar taxes from all the stars which dare to enter its gravitational province.

Gas sucked from stellar surfaces joins with similar material already in orbit around the black hole. The result is an accretion disk. If you could see such a disk close-up, you'd notice that the parts of it nearest to the black hole are rotating the fastest. At the outer edge, the rotation speed is very much less. Exactly the same principle works for planets in orbit around the Sun.

Now we're close to solving the riddle of energy production in systems which harbor massive black holes. A tremendous amount of friction occurs between the different layers of the orbiting accretion disk. The outer parts are trying to slow down the inner parts; the inner parts are trying to speed up the outer parts. A great release of energy occurs as the competing layers slip and slide against one another — energy that's ultimately supplied by the gravitational field of the black hole.

Imagine the last moments of an ill-fated cloud of star matter as it plunges on its terminal journey towards a black hole. Picture its furious chase around an inescapable whirlpool at the inner edge of the accretion disk. The doomed cloud gathers speed as it falls through steeper and steeper portions of the powerful gravity field. Some of this frenzied motion is passed on, as frictional heat, to layers a little farther out in the disk.

What's the end result? Simply this: There's a continuous passage of "high-grade" energy from the innermost parts of the accretion disk to the slower moving outer parts. Effectively, the black hole's gravitational energy is being converted into heat — heat to power the radiation machine of an active galaxy. Almost half of the matter which falls into the accretion disk could be converted into electromagnetic radiation: radio waves, visible light, X-rays, and so on.

From M-87 to accretion disk: Our diversion into the mechanics of black holes has taken us far from our starting point. Just how confident can we be that massive collapsed objects finance the extravagant energy spending of active galaxies? And what characteristics distinguish one type of active system from another?

Since 1963 — the "year of the quasar" — our basic concept of the nature of the universe has profoundly changed. No longer does space seem calm and orderly. We've glimpsed scenes of unimaginable violence both within our galaxy and beyond: matter-crushing gravity pits, galaxy-tearing tidal forces, and super-galaxies with a hundred times the energy output of the Milky Way. And, as we look back through time and space, to earlier epochs of the universe, violent events become more and more commonplace. Distant galaxies burn brighter, it seems, than those nearer to home. Out towards the very edge of the observable universe, 10 billion light-years or more away, lie the brightest and most energetic systems of all — the infamous quasars.

Even through giant telescopes, the quasars don't give up their secrets easily. No stars, no dust lanes, have ever been seen within a quasar. Their innocent, dim, blue starlike appearance makes it hard to conceive that they're probably the most energetic objects in existence.

But let's look a little more closely at the faint trickle of light reaching us from a quasar. What clues to the quasar's nature can the spectrum of the 10 billion-year-old signal give us?

Imagine the scene over 16 years ago, when that question was asked for the first time. The strong radio source 3C 273 had just been identified with an innocuous-looking 12th magnitude blue starlike object in Virgo: number one in a series of similar very localized radio sources to be linked with optical counterparts. Maarten Schmidt, an astronomer at Mt. Palomar, took up the challenge of the mystery object. What kind of star could be such a powerful radio beacon?

Schmidt took a spectrum of the light from 3C 273. What he found was astonishing. Crossing the spectrum in a number of places were bright, broad lines — the kind of lines you might expect in the light from a hot gas. But the lines were in all the wrong places. No known element, or combination of elements, could have produced the quasar's odd spectrum. Or so it seemed.

It was then that Schmidt hit upon a brilliant, but very simple, idea. What if those lines belonged to a familiar element, but were emitted by something moving at very high speed? Light waves — any waves — undergo a wavelength change if their source is moving. If the source is approaching, the wavelength is reduced, and a *blueshift* results; if the source is receding, the wavelength increases, and a *redshift* (a shift to the longer wavelength, or red, end of the spectrum) results. To anyone who's heard a passing siren, the phenomenon will be very familiar. Its scientific name is the Doppler effect.

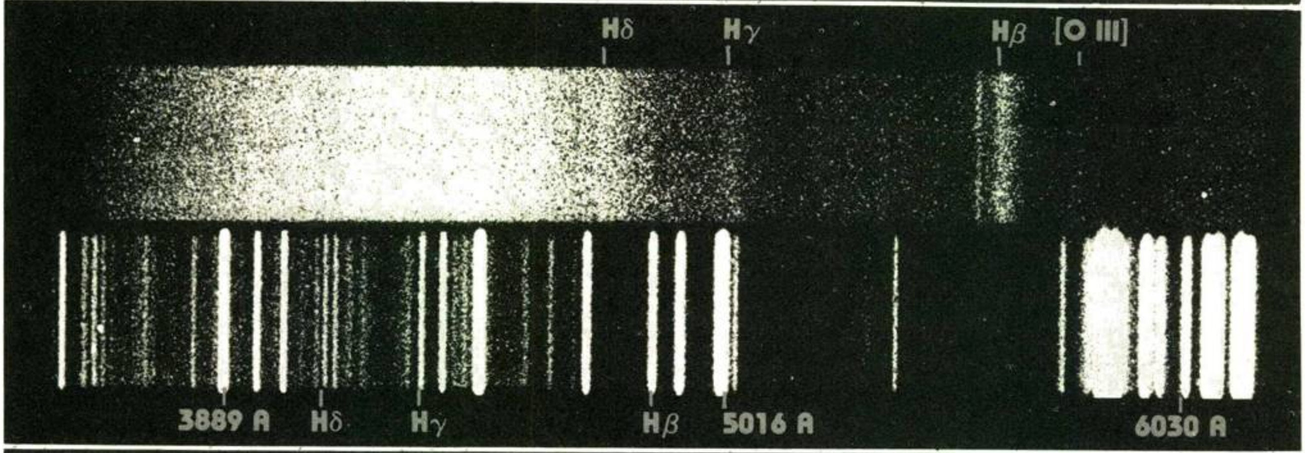
Schmidt's realization was that 3C 273's emission lines were really those of hydrogen, but vastly redshifted from their normal positions. If the redshift is a Doppler shift, then 3C 273 must be hurtling away from us at about 1/10th the speed of light.

As it turned out, even 3C 273's redshift is pretty modest in comparison to that of many of its fellow quasars. Recession speeds exceeding *90%* that of light raise few astronomer's eyebrows today.

Yet quasars have become the focal point for a major debate. The famous "Redshift Controversy" is centered on the question: "What's the origin of the quasar's enormous redshifts?" Either the redshifts

Most quasars are virtually indistinguishable in appearance from much nearer foreground stars, but all are identifiable by their enormous redshifts. While many, such as 3C 48, 3C 9, and 3C 196, are marked by strong radio emissions, some, like BSO 1, are "radio quiet." Why some quasars are radio sources and others are not is still a mystery. Hale Observatories photographs.

A Quasar Spectrum



The spectrum of the quasar 3C 273 is shown above. The lower spectrum consists of hydrogen and helium lines and serves to establish the scale of wavelengths. The upper part is the actual spectrum of the quasar. The Balmer lines of hydrogen, labeled Hβ, Hγ, and Hδ, are at longer wavelengths in the quasar spectrum than in the comparison spectrum. The redshift of 16% corresponds to a distance of two billion light-years in the expanding universe. Photograph courtesy of Maarten Schmidt, Hale Observatories.

are cosmological, that is, they're caused by the overall expansion of the universe, or they're a local phenomenon. "Local," in the same sense, means that the quasars get their high speed from something other than cosmic expansion — implying that they're a lot less remote than a cosmological interpretation of their redshifts would suggest.

The controversy still rages as furiously as ever. And, as you might expect, supporters of either view have their problems — and their evidence. Those favoring a cosmological redshift are in the great majority, though, so let's consider their side of the argument first.

Recall 3C 273. If its 1/10th light-speed recession is really cosmological in origin, we arrive at a figure of around 3 billion light-years for its distance from the Sun. Quasars with higher redshifts would be correspondingly further away. In the extreme case of an object flying from us at 9/10ths light-speed or more, we'd derive a distance value in the range of 10 to 18 billion light-years. OQ 172, the most remote quasar known, lies right at the high end of this distance range.

If quasar redshifts are due to the overall expansion of the universe, then one fact stands out very clearly: quasars are extremely remote. But distance in itself isn't too significant. We shouldn't be surprised to find the early universe, a few billion years after the Big Bang, inhabited by a large number of unfamiliar light-emitting objects.

The real problem lies with the prodigious quasar energies which enter the calculations the moment you accept the distances implied by cosmological redshifts. Think back, once more, to our friend 3C 273. At 3 billion light-years, it's 1,500 times farther from the Sun than our neighboring spiral in Andromeda. Yet 3C 273 is easily spotted with a modest amateur telescope. By comparison, our own Milky Way would challenge the light grasp of even a 200″ instrument if viewed from the same distance.

Cosmological redshifts imply enormous quasar luminosities. Let's consider a few of the energy statistics if quasars really are the most distant of all cosmic objects.

3C 273 turns out to be not only one of the closest, but also one of the most energetic members of its class. At optical wavelengths, it outshines a normal spiral galaxy by a factor of around 250 to 1. In the infrared, it's even more impressive, beaming out over 100,000 times more radiation than a system like the Milky Way.

Activity in the radio wave region is another quasar feature. About half of the known quasars are strong radio sources, packing almost enough energy into the long-wavelength end of their spectra to rival their visible output.

Even X-ray emission has been detected from a handful of quasars. Perhaps more examples of very short wavelength emission from quasars will be found in the future, with the development of increasingly sensitive X-ray detectors.

As if galaxy-dwarfing energies aren't enough to comprehend, quasars go one step further. They vary, often dramatically, in brightness. Both in the radio and optical regions, fast changes in energy output have been measured. 3C 273's radio output, for example, has varied irregularly since its discovery, brightening by a factor of 3 over a 3 year period between 1963 and 1966.

In extreme cases, the variability is quite exceptional. The quasar 3C 446 has been known to double in optical brightness in less than a day. It's a member of a sub-class of quasars called *optically violent variables* — a group of objects which create an especially acute headache for the theorist.

The problem is simply this: it's impossible for anything, whether it be a star, a galaxy, or a quasar, to vary in brightness in a time less than it takes for light to cross the main energy source. The time scale of change in brightness effectively sets an upper limit to the size of the source.

In the case of a quasar which takes only a day or so to double its output, we're led to the fantastic conclusion that its energy source is little larger than our own solar system. What could this exotic source be?

A supermassive black hole must certainly rank as one of the prime candidates, and suggests the first tenuous links between quasars and active galaxies. Maybe all high-energy systems, quasars and active galaxies, are powered by the radiation from swirling accretion disks around massive black holes. A hundred million solar-mass black hole, a light-day across, could be the quasar's powerhouse.

Other theories, many of them calling for energy sources even more incredible than a big black hole, have been devised to account for the quasars. One, in particular, evokes *white holes* — time-reversals of black holes — to explain the quasars' intense activity. The white hole theory suggests that matter swallowed up by black holes in other parts of time and space, perhaps even in other universes, can gush back up into our universe again. These cosmic energy wells could be what we call quasars.

In the years following their initial discovery, many new clues have been found to help in unraveling the mystery of the quasars. Active galaxies, high-powered star cities, have appeared on the scene, providing what seem to be some of the crucial missing links between quasars and normal galaxies. We're seeing an exciting new order emerging with quasars possibly playing a leading role at the high-energy end of the galactic spectrum.

Before we move on to take an in-depth look at the active system, let's return for a moment to the Redshift Controversy. Let's ask the question: What if the quasars are a lot closer to us than a cosmological interpretation of their redshifts would suggest? Could it be that the redshifts have nothing at all to do with cosmic expansion?

One man who believes so is the distinguished astronomer Halton Arp. As evidence, he cites a fascinating group of photographs (see "The Redshift Problem," ASTRONOMY, Sept. 1978) which seems to show luminous bridges of matter linking several quasars and galaxies with discordant redshifts. The galaxies have very much lower redshifts than the quasars which Arp thinks are joined to them. The million dollar question is: Are the matter bridges real? If not, if they're really an illusion created by overlapping images, then the argument against cosmological redshifts is destroyed. Conversely, if Arp and his colleagues continue to unearth examples of anomalous galaxy-quasar associations, the case for a new interpretation of quasar redshifts will be greatly strengthened.

The quasar problem would certainly be eased if we could see a little more of their internal structure. Very few quasars appear as anything other than starlike points. Those that do, reveal only the most tantalizing glimpses of a dim, hazy periphery around a bright central source.

What would a quasar look like at close range? Would fainter, but much more extensive structures be seen around the tiny, laser-bright nucleus — the embryonic arms, perhaps, of an evolving spiral galaxy?

Enter the active galaxies: Bewildering in their variety of forms, they're now being considered as possible "missing links" in the complex chain of evolution from quasars to the normal galactic systems we're familiar with.

Active galaxies can be pretty well grouped by the total amount of nonthermal energy they launch spacewards. The nonthermal source in most active systems is probably "synchrotron" emission from high-energy electrons — the type of radiation characteristic of charged particles speeding through strong magnetic fields.

How can we tie everything together that we know about quasars and active systems into a coherent scheme of galactic structure and evolution? Are normal galaxies evolved from quasars? Bring only your imagination and let's journey to the dawn of the Universe in search of answers.

Clearly at the top of the energy league for active systems are the N-galaxies. And, although these objects lie closer to us than the quasars, we're left in little doubt of their quasar-like properties. The N-galaxies are compact radio sources. They're highly variable, often have broad, strongly redshifted emission lines, and beam out much of their energy in the infrared. The list of similarities is impressive.

From photographs, the "Jekyll and Hyde" nature of N-galaxies becomes evident. Long exposures reveal the unmistakable swirls of immature spiral arms: a strong indication that these objects may be distant, but direct ancestors of today's normal galactic systems. On short exposures, though, a very different picture emerges. Now, the dim periphery of an N-galaxy almost fades from view, and we're left with...a quasar?

Here, then, is an all-important question: Are quasars just very remote, luminous N-galaxies? Are quasars the dazzling cores of very young but more extensive galaxies? If they are, then the first vital link in an intriguing galactic chain of evolution will have been forged.

The testimony of the N-galaxies is clear enough. Their brilliant, tiny cores are virtually indistinguishable from true quasars of modest energy. Surrounding those bright, blue cores, though, are more familiar structures — the reddish envelopes we'd normally associate with the ancient star populations of giant ellipticals. N-galaxies are the ultimate in cosmic variety shows.

Right on the borderline between quasars and N-galaxies — a cosmic "missing link" — is the curious 3C 120. Its super-luminous core — quasar-like in all its features — spews out vast amounts of energy from within an otherwise normal galactic envelope.

The quasar-active galaxy link looks promising. But still we need more evidence, and some more clues on the ways in which normal galaxies might evolve from compact ultra-high-energy nuclei. Where should we look?

As it turns out, there are a large number of quasar-like objects, closely related to the N-galaxies, which we haven't yet considered. Most of these fall into an exciting class of high-power spirals — the *Seyfert galaxies.*

There are no hard and fast rules to determine exactly which objects should be called Seyferts. The transitions from quasar to N-galaxy and from N-galaxy to Seyfert are pretty smooth, with many instances of objects having "identity crises."

Seyferts, on the whole, tend to be not as distant as their more energetic cousins. From a billion light-years, or less, their super-luminous starlike nuclei burn bright over a wide range of the electromagnetic spectrum. But now, the much dimmer peripheral structures — so elusive in the remote N-galaxies and quasars — begin to tell a story of more familiar galactic development.

Are the Seyferts just normal galaxies with active quasars at their cores? If so, could those central quasars be stupendous geysers from which matter is thrown out to build normal galaxies? The answers may lie within a Seyfert's spectrum.

When we compare a quasar's spectrum to a Seyfert's, we're struck immediately by their remarkable similarity. Every significant feature of one has its analog in the other. Similar spectra almost certainly point to similar underlying processes — but what could those processes be? The message of their spectra is clear. These highly active systems harbor two very different mechanisms for producing radiation.

The big energy-generating mechanism is the one which supplies the powerful continuum output of an active nucleus. "Continuum" just means that this type of radiation is spread over the entire spectrum instead of being concentrated at specific wavelengths. In a quasar, or any active system, it's the continuum component which carries the lion's share of the total energy output.

The second energy generation mechanism is that which produces the bright, wide emission lines in a quasar's or Seyfert's spectrum. These lines are actually pretty unimportant energy-wise; their contribution is extremely modest in comparison to the powerful continuum. Yet emission lines are a vital source of information on the regions where they're formed.

An emission spectrum is almost always linked to the presence of hot, low-density gas clouds. We'd expect those clouds to be made up almost exclusively of hydrogen and helium, the dominant elements in the universe. Atoms within the clouds soak up high-energy continuum radiation, become ionized (stripped of one or more electrons), and then emit radiation of very characteristic wavelengths as they recombine.

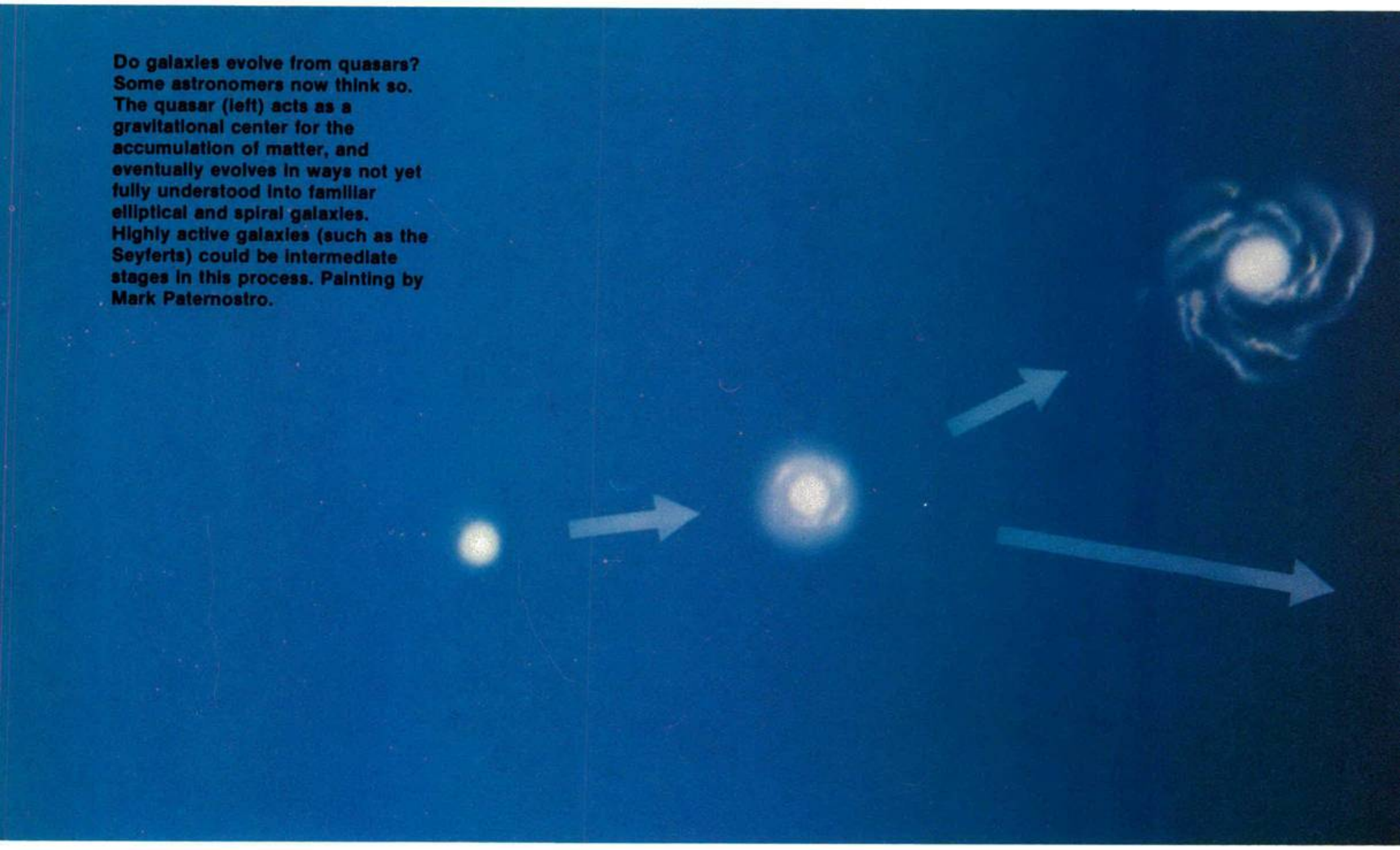
The conclusion from quasar and Seyfert emission lines, then, is that these objects contain hot gas clouds. We can go one step further, though. From the finite width of each line, we can deduce that these clouds are moving at high speeds — typically several thousand kilometers per second. Some of the emitting regions are receding from us, relative to the quasar core, while others are approaching. The significant redshifts and blueshifts that are imposed on the radiation result in the observed broadening of the emission lines.

Cool clouds of matter also seem to be associated with quasars, their presence revealed by dark absorption lines. Are both the electron clouds and the hot and cool gas clouds actually debris blasted from the rim of a massive black hole's accretion disk?

Back to the continuum. Apart from sheer strength, rapid variability is the other outstanding feature of an active system's continuum. We talked about it earlier in connection with quasars. Big changes in output can occur in a period of just a few days, implying that the main energy source combines a unique and exotic blend of properties. The central source must be as powerful as a hundred normal galaxies — but little larger than the solar system. Could the same fantastic machinery at the heart of a quasar also be the

The brilliant cores of Seyfert and N-type galaxies imply that some highly energetic event is taking place. In some cases, the brightness of these galactic centers have been observed to vary within a period of weeks, indicating that the source of the activity is in reality extremely small—like a quasar. Although not as profligate in energy release as a quasar, these active galactic cores display other quasar-like characteristics. Is there a connection? Painting by Rick Sternbach.

Sternbach



Do galaxies evolve from quasars? Some astronomers now think so. The quasar (left) acts as a gravitational center for the accumulation of matter, and eventually evolves in ways not yet fully understood into familiar elliptical and spiral galaxies. Highly active galaxies (such as the Seyferts) could be intermediate stages in this process. Painting by Mark Paternostro.

driving force for a Seyfert galaxy?

The super-massive black hole enters the scene again. Here, in its surrounding vortex of colliding star matter, we find the ideal source to generate heat to fuel the continuum emission of an active galaxy. Electrons are fried to high temperatures in the accretion disk. Escaping the tortured core at near-light speeds along magnetic field lines, they shake off their newly-gained energies as radiation at all spectral wavelengths.

Is this the way energy is produced and released in quasars and active galaxies? The growing weight of opinion is that it is. The black hole-accretion disk model certainly solves the problem of colossal energies coming from tiny volumes. It's effective, too, in accounting for the fast and wide variations in output. An accretion disk isn't a steady, static energy source — it flares and erupts as new tongues of stellar matter fuel its fiery whirlpool.

Strong X-ray emission is a major feature we'd expect to find in a black hole-powered system. Although the study of X-ray sources is still in its infancy, the early results are really encouraging.

At least 3 quasars are known X-ray sources, and they're amongst the very nearest members of their class. As the science of X-ray astronomy matures, and instruments are developed to detect even weaker sources, we can expect a quantum jump in the number of known X-ray emitting quasars. It's quite possible that all quasars are active in the X-ray region.

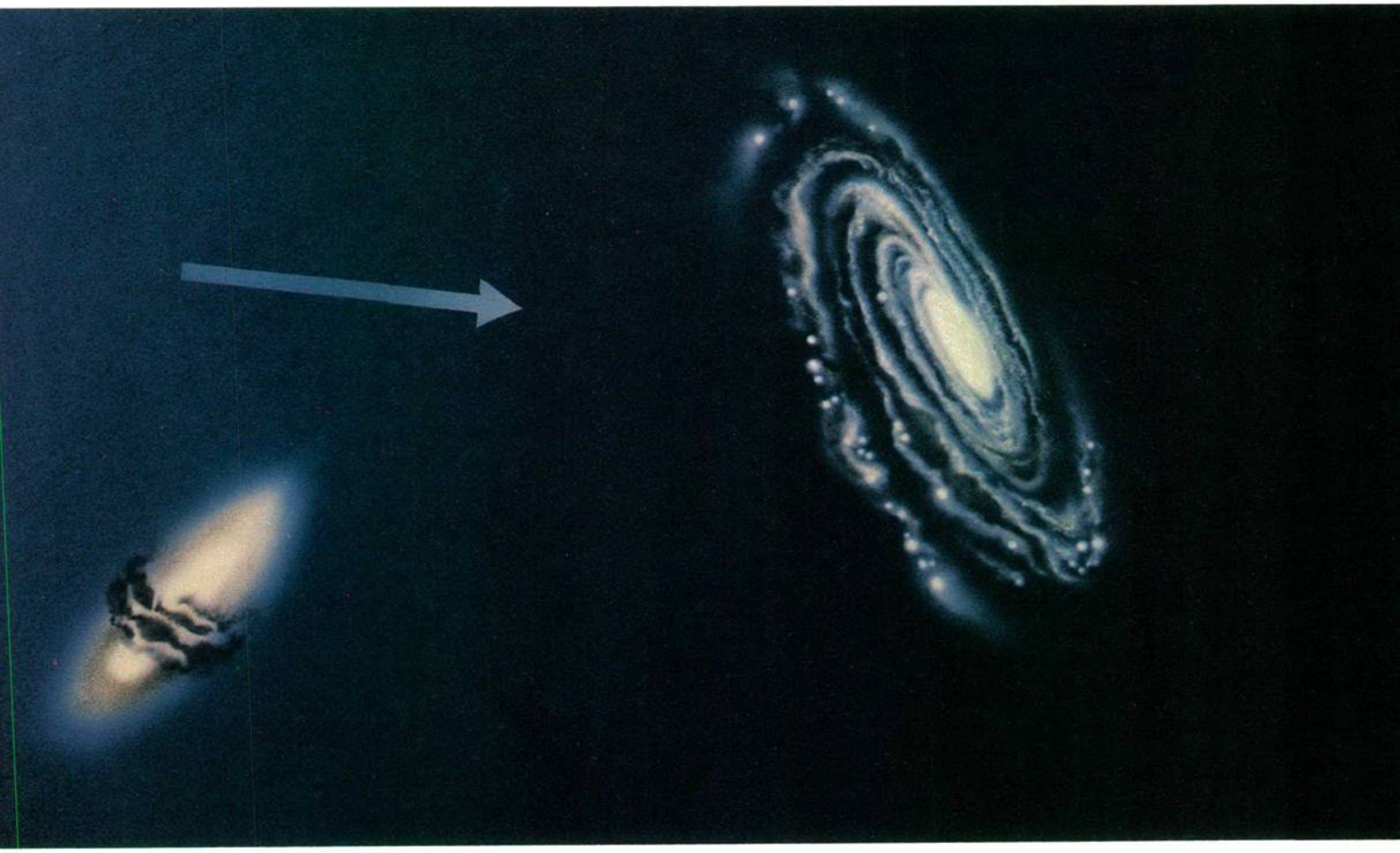
Currently, the 3 X-ray celebrities are 3C 273 (the "original" quasar), MR2251-178, and 0241+622. Of these, 3C 273 is the most distant at a mere 3 billion light-years. The other objects lie, partially veiled, behind thick banks of dust in our own galaxy. When allowance is made for the effects of obscuration, MR2251-178, at around 1.2 billion light-years, turns out to be one of the brightest quasars known — brighter even than the super-quasar 3C 273.

Many Seyferts, too, are strong X-ray emitters. Their close resemblence to quasars in this respect is convincing evidence that the same kind of energy factory operates within each.

Now let's jump to the opposite, long-wavelength, end of the spectrum. Radio emission is probably one of the least understood of all the puzzling properties associated with quasars and active galaxies. It also brings into consideration the largest known single objects in the universe — the giant radio galaxies.

Radio waves are carriers of pretty low-grade energy, as far as electromagnetic radiation goes. Yet quasars beam out as much energy in the radio region of their spectra as normal galaxies, like our own, emit at all wavelengths. Where does all that radio energy come from?

The first, and most important, clue is that the radio waves we receive from quasars are strongly



polarized. "Polarization" just means that the electric and magnetic fields of the radio waves, instead of vibrating randomly in all directions, are constrained to vibrate in a single direction. There's only one realistic way you can account for this occurrence in a quasar, and that's with the "synchrotron effect."

Remember synchrotron emission? We talked about it earlier and mentioned that it's caused by electrons being accelerated to high speed in a weak magnetic field. Synchrotron emission which is always polarized would explain not only the powerful radio-wave activity of quasars (and of all high-energy galaxies) but every component of their continuum.

Variability is a key feature of the continuum. Does the synchrotron effect allow for that, too? Yes — if we assume that clouds of electrons, a few light-years across, are thrown out from the central source at irregular intervals. On the basis of all our quasar observations, including measurements of the quality and variability of the continuum, that turns out to be a very reasonable assumption indeed.

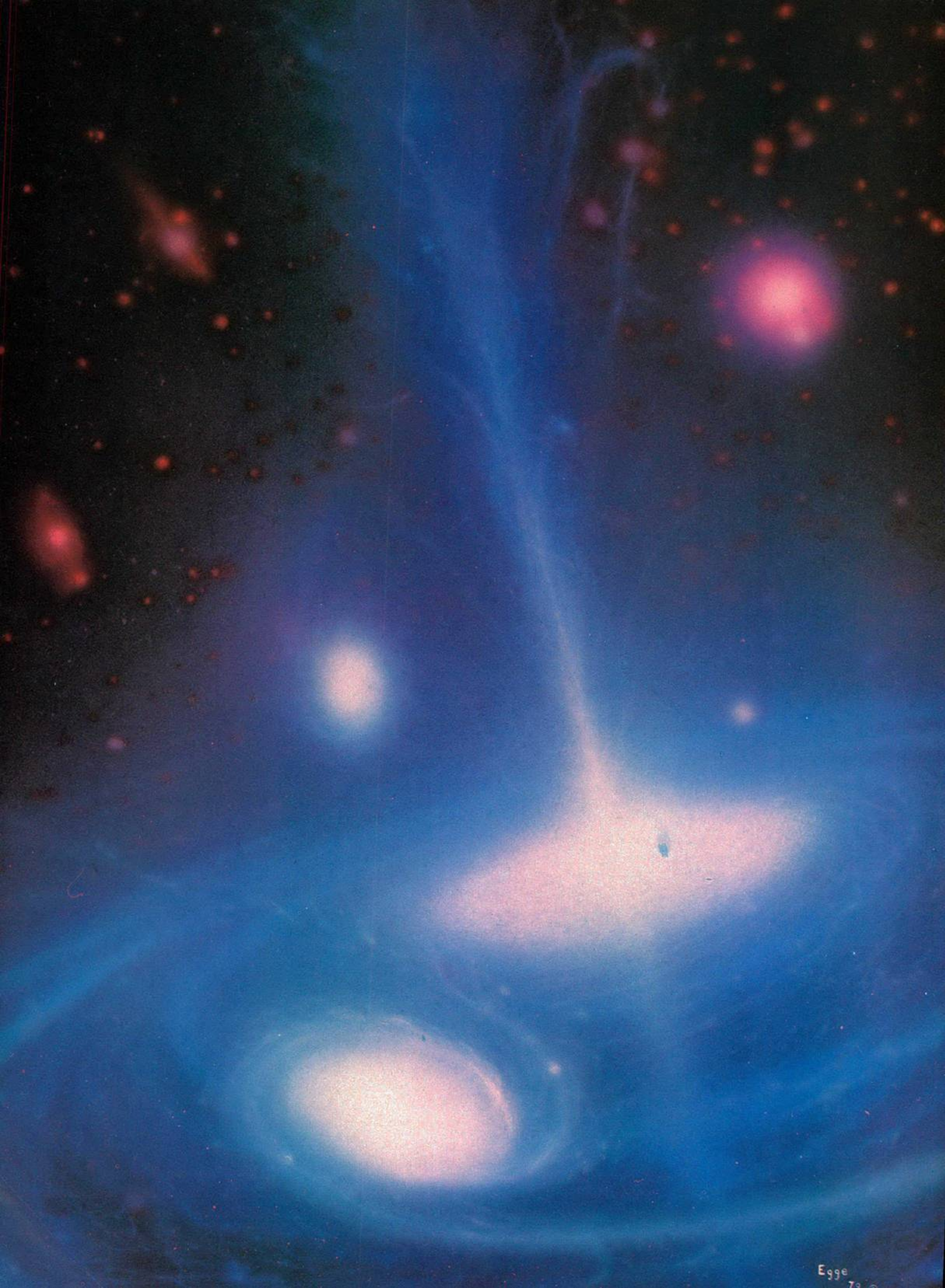
Powerful radio emission isn't only confined to the quasars. Bright members of the N-galaxy and Seyfert fraternities outshine a normal galaxy by a million to one in the radio region. Giant radio galaxies, too, can be quasar-rivaling in their output. And in each case, these active systems harbor central energy sources which are both enormously powerful and extraordinarily small.

How can we tie everything together that we know about quasars and active systems into a coherent scheme of galactic structure and evolution? Are normal galaxies evolved from quasars? If so, do N-galaxies, Seyferts, and radio galaxies represent some of the intermediate stages of that evolution? Bring only your imagination and let's journey to the dawn of the universe in search of answers.

Time: 2 billion years after the Big Bang. All around, an unfamiliar universe prepares for the initial stages of galactic synthesis — a synthesis which 15 billion years later will have structured the cosmos as we know it today. It's the time of the first quasars.

What would be the scene from a star-ship hovering ten thousand light-years from the surface of a newly-born quasar? Would we see matter and energy pouring from the edges of a searingly hot accretion disk? Would we see the glowing tendrils of an evolving galaxy springing from the vortex around a supermassive black hole? Yes, perhaps. The occasional quasar envelope, glimpsed from afar, lends support to the idea. And, from all we know, supermassive black holes rank among the top candidates for the quasars' energy source.

Billions of years pass. Some of the quasars' nuclei have become less active, their peripheries enlarged and more developed. On a planet orbiting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a star of a very different galaxy, far away in time and space, astronomers use new names for these evolved quasars. The names — "N-galaxy" and "Seyfert galaxy" — seem to imply that the objects they describe fall into very different groups from the quasars. They suggest a sudden discontinuity in the evolution of quasars which, in reality, never happened.

Most quasars may have evolved in this way, from very small energetic nuclei to less active, full-fledged galaxies. Those quasars which started life with a single, central, supermassive black hole may have been the seeds from which normal galaxies, like the Milky Way, eventually grew. But what bizarre species would sprout from a quasar with multiple black holes at its core?

Black holes, as it turns out, aren't socially inclined. Placing more than two of them inside a quasar would quickly make the core dynamically unstable. Calculations show that one of the black holes would be smartly and permanently ejected from the nucleus, leaving the remaining two as a curious binary pair.

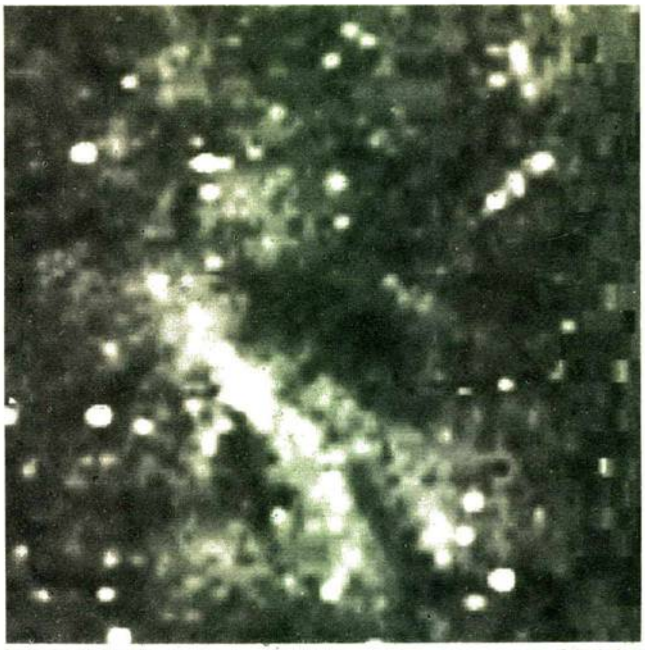
Quasars with twin, symmetrical radio sources have been observed and aren't uncommon. Binary systems, each member of which is a supermassive black hole, might explain their appearance. And these systems could also account for the puzzling double structures in radio galaxies.

One popular theory suggests that there's a direct evolutionary link between quasars with double radio sources and the much larger radio galaxies. Objects like M-87 — the second closest strong radio galaxy — may have developed from the core and expanding radio "lobes" of a super-compact quasar.

The early universe may have been the home for a number of different varieties of quasar. Some, as we've seen, almost certainly evolved to become N-galaxies and Seyferts. Others may have grown into radio galaxies — supergiant ellipticals with quasar-like energies.

But what of the more "law-abiding" citizens of the galactic community? Where did the "normal" spirals, and ellipticals, and irregular systems of the Local Group and other clusters of galaxies come from?

The majority of present-day galaxies may never have passed through an active evolutionary phase. For them, there was no "quasar connection." The earliest ancestors of many systems, particularly the dwarf and irregular galaxies, were probably rotating, local condensations of matter in the universe a few billion years after the Big Bang. But what of the rest? Can we point to any apparently mature galaxies which still bear the signs of an active youth?


Sagittarius A in infrared

Caltech photo

At the center of the Milky Way is a pretty strong source of radio waves, which astronomers call Sagittarius A. It's small — no more than 30 light-years across — and it harbors an even smaller, infrared source. Sagittarius A is just one of several odd features of our galaxy's core — a region where the stellar population is a million times more dense than in the solar neighborhood. For instance, there are signs that the core was blasted by an explosion in the fairly recent past. Two expanding regions of gas and dust — embryonic spiral arms — may be the debris from that violent event. The composite picture of the Milky Way's nucleus which emerges, is one which has some uncanny resemblances to a scaled-down quasar.

All the essential elements of quasars and other active systems are found in miniature within our own Galaxy's core: An infrared source, a synchrotron source, fast-moving hot gas clouds, and slower-moving cool clouds are all present — without exception. Is the strange source at the center of the galaxy a dead, or dying, quasar?

Astronomers today are slowly uncovering the "roots" of normal galaxies, including spiral systems like our own. The tendrils of logic, fed by revealing new observations and penetrating theoretical insight, are stretching back through time and space to an earlier, more violent universe. And the "quasar connection" is emerging. From across a 10 billion year time chasm, we're beginning to see clearly the fabulous evolutionary bridges linking quasars with more familiar galactic systems.

David Darling received his doctorate from the University of Manchester (England). For his thesis topic, he studied the dynamics of multi-envelope planetary nebulae, and has written about these objects in ASTRONOMY.

Against the glowing background radiation of a young universe, cosmic expansion reddens the light of the receding galaxies in the distance. In the foreground a giant black hole devours an infant galaxy as others, their light blueshifted by their approach, are inexorably drawn in by the black hole's enormous gravitation. Painting by David Egge.

ASTRONOMY forum

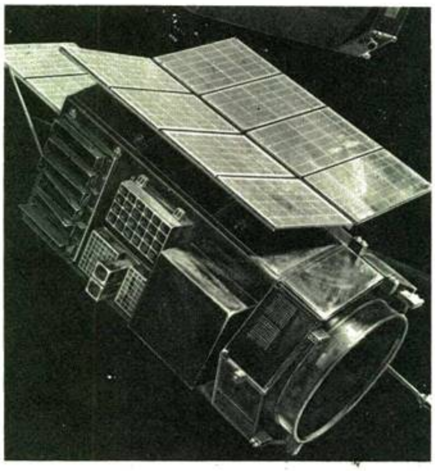
The Path to Discovery

This is a story about the process of discovery, a process involving a little luck, a little timing, and a lot of persistence. It also involves the assistance of amateur astronomers all over the world. It's about the investigation of the X-ray properties of a class of stars known as cataclysmic variables, and it details the discovery of X-ray pulsations in these objects.

Let's introduce the cast of characters: first, the stars. Cataclysmic variables have been observed by amateur astronomers since 1850. A cataclysmic variable, we now know, is a binary system composed of a low-mass red star and a degenerate white dwarf star. Because these partners are no farther apart than the Earth and the Moon, the tidal forces between them are tremendous. Stellar material, streaming off the red companion toward the white dwarf, intercepts a disk of material which surrounds the white dwarf. Where the gas streams impact the disk a shock is created; this brilliant, glowing hot spot at the impact point causes a peculiar "hump" in the visual light curve of these systems. The disk is composed of hydrogen gas; it is viscous and lumpy. The friction between the various irregular lumps of orbiting material gives rise to a pronounced "flickering" of the star in blue and ultraviolet light. Disk material circles the white dwarf in ever smaller orbits until it eventually hits the white dwarf surface.

Adding so much material to the degenerate star's surface eventually causes an explosion. No one is quite sure how it works; it may be due to a thermonuclear runaway or the accretion of an excess amount of material onto the white dwarf. In any event, when it happens, the result is spectacular. When the prototype object in this class (the first dwarf nova discovered, U Geminorum) flares up, it increases its visual brightness by one hundred times.

Next in the cast of characters is the satellite observatory: NASA's High Energy Astronomical Observatory satellite, "HEAO" for short. HEAO-1, the first of three satellites designed to make comprehensive study of the high-energy universe, was to conduct an all-sky survey of radiation ranging from the softest X-rays (0.1 keV) to 10 MeV gamma rays (a range of 1:100,000 in energy). The time variability and spectra of X-ray sources already known could also be studied and, in addition, the experimenters hoped to find many new sources because HEAO's detectors were better than previous X-ray instruments.



HEAO-1 was launched on Aug. 12, 1977, and continued to take data until Jan. 9, 1979. During its first six months, the satellite, operating in a scanning mode, made a complete map of the X-ray sky. Later in the mission, the satellite was devoted mostly to pointing at selected targets.

A decision to survey X-ray emission from cataclysmic variable stars using HEAO-1 was motivated by the previous detection of X-rays from the dwarf novae SS Cygni and AM Herculis. We hoped to measure X-rays coming from dwarf novae that happened to be undergoing visual outbursts at the time they were being scanned by HEAO-1. Indeed, on the day HEAO-1 was launched, a prominent dwarf nova in the southern sky, Z Chamaleontis, was undergoing a "supermaximum." However, while the first HEAO-1 data showed many exciting new features in the X-ray sky, Z Cha was not one of them. Several weeks rolled by. No X-ray emission was detected from several other dwarf novae which also had eruptions while HEAO-1 scanned them in its first few weeks of operation. We were mildly puzzled. But it was not until the end of October 1977 that the first big surprise came.

But before we go on, let's introduce the final set of characters: variable star observers. These men and women, with binoculars and small telescopes, were indirectly the real discoverers of the X-ray pulsations in dwarf novae. Certainly these discoveries would not have been made without them.

On Oct. 18 we received a phone call at Caltech from members of the AAVSO. They informed us that U Geminorum was beginning an optical outburst. We had given both the AAVSO and the Variable Star Section of the Royal Astronomical Society of New Zealand (VSSNZ) HEAO-1 ephemerides of 150 cataclysmic variables, and many members of these organizations had volunteered to keep a vigil on the program stars. They

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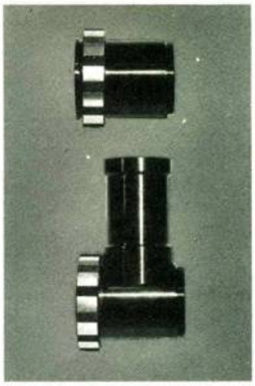

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would alert us to sudden changes in the optical brightness of any survey star in the HEAO-1 scan path. The directors of these organizations, Ms. Janet Mattei of the AAVSO and Mr. Frank Bateson of the VSSNZ, coordinated this program and sent us the visual light curves of erupting dwarf novae for comparisons with the X-ray light curves.

The data from the A-2 experiment, which was the experiment on HEAO-1 used for the survey, were shared jointly by several institutions. The California Institute of Technology, the University of California at Berkeley, and the Jet Propulsion Laboratory in Pasadena, California, shared the low energy ("soft X-ray") data, while the Goddard Space Flight Center had charge of the high energy ("hard X-ray") data. For the week in which U Gem had an outburst, it was Berkeley's turn to process the low energy data, so we immediately notified them of the U Gem outburst. A look at the Oct. 18 HEAO-1 data, however, revealed no evidence of X-ray emission from a source at the position of U Gem. It appeared that this dwarf nova, like many others, was not an X-ray emitter.

Our surprise came the next day. An excited scientist from the Berkeley group told us that an extremely bright source had suddenly appeared in the Oct. 19 data at the location of U Gem! Since the satellite was in a scanning mode at the time of this observation, it took only a few 15-second "snapshots" each day. There was no way to affirm whether the apparent day-long delay in the soft X-ray brightness was due to a real lag in the turn-on of the soft X-rays, or whether it was simply due to poor sampling of a highly variable soft X-ray source.

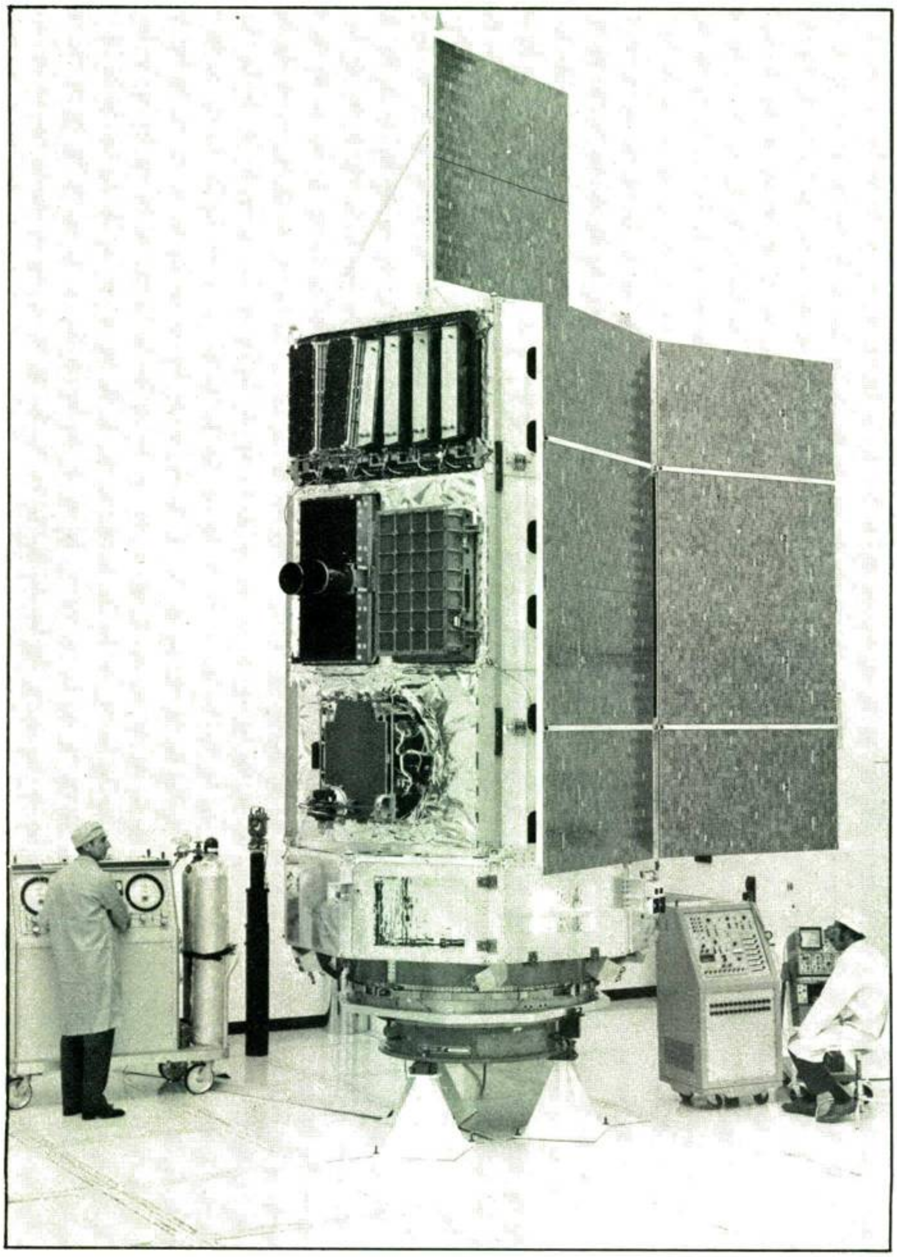
With this new discovery, our hopes for the survey were renewed. In November, I flew to the Cerro Tololo Inter-American Observatory in Chile to use the 36″ telescope for simultaneous photoelectric observations of a few prominent cataclysmics which HEAO-1 was scanning. Among these stars was VW Hydri, which happened to undergo both a normal outburst and a supermaximum while HEAO-1 observed it. I also did photometry on RR Pictoris, the brightest of the ex-novae, and AE Aquarii, a very active novalike object. I was dismayed to learn, upon my return to the States, that no X-ray emission had been detected from any of these stars.

Why were some variables turning out to be X-ray sources and not others? Was it simply that SS Cyg and U Gem were closer than the other cataclysmic variables? Or was the extremely low X-ray temperature measured for U Gem during the October detection telling us that these binaries were too cool to be detectable as soft X-ray sources?

The mystery deepened when, on Dec. 12, 1977, we had our first scheduled pointing at cataclysmic variable SS Cyg. Unfortunately — or so we thought at first — the dwarf nova wasn't undergoing an outburst at the time of the pointing. However (another big surprise), hard X-ray emission from a very hot gas was detected from the dwarf nova. Furthermore, these hard X-rays were observed to "flicker" on a time scale of minutes. It was begining to look as if the theoretical models for X-ray emission from cataclysmic variables would have to be revised.

We spent the next few months going over all the existing HEAO-1 X-ray data and superposing the numerous scans for each day to see if any new weak X-ray sources would emerge from the noise of the X-ray sky background. This technique, when used to search for soft X-ray emission from the 150 stars in the survey, produced no detections for 20 dwarf novae which were undergoing optical outbursts during HEAO-1 scans. It also produced two new sources: the first detection of soft X-ray emission from the dwarf nova EX Hydrae during optical quiescence, and a possible detection of very soft X-rays from the dwarf nova AY Lyrae, also during quiescence. Both of these sources showed evidence that gas in the binary system might absorb the X-ray emission and be part of the reason why so few of the cataclysmics were being detected at X-ray wavelengths.

Time wore on. By May 1978 it became apparent that the low energy detectors of the A-2 experiment were running out of gas. We shut off the gas supply to the detectors to conserve what little remained for one or two more "targets of opportunity." But it



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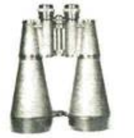

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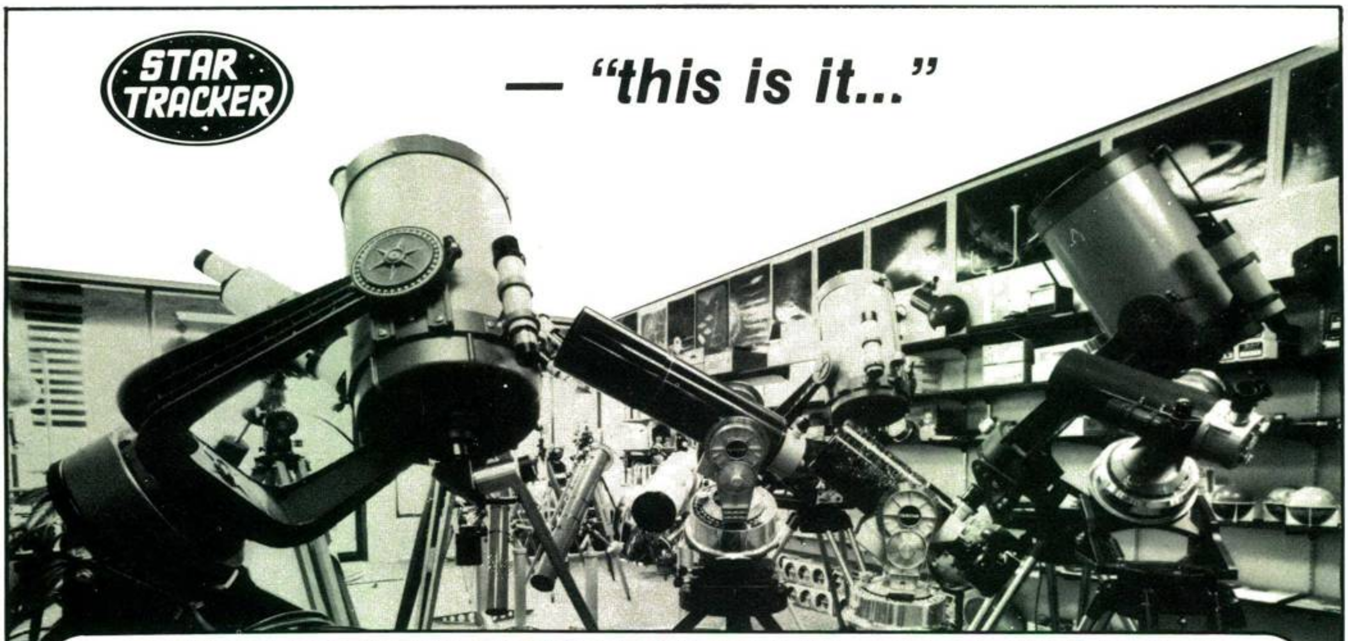

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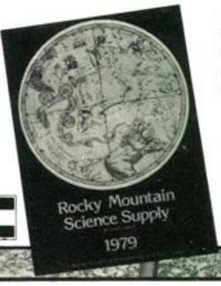

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looked like the end of the HEAO-1 soft X-ray experiment.

Then, two weeks later I got a telephone call from Jim Morgan, an AAVSO member who lives in Prescott, Arizona and who had been an active participant in the Cataclysmic Variable Survey. "Your star is up!" Jim exclaimed. He hadn't heard about the detector shut-down.

I contacted the head of the Caltech X-ray group, Professor Gordon Garmire, a principal investigator on the HEAO-1 A-2 experiment. Although Professor Garmire agreed that the erupting SS Cyg was a worthwhile target for a last detector pointing, he was not optimistic about getting a pointing scheduled on such short notice. Many satellite personnel, officers, and engineers at Goddard had to be contacted and given specific instructions for the delicate business of reactivating the detector.

All the observing slots for the next week had already been scheduled for other experiment pointings; however, we did get scheduled for a 6-hour observing period for the following day. We worried though, because the dwarf nova was already in its fifth day of outburst, and we thought it might not stay bright until the pointing.

Members of the AAVSO kept an all-night vigil and assured us that the star was still at peak brightness. The pointing was carried out the next afternoon. At the time, we had no idea if the gas supply would hold out for the duration of the observation, or whether the very delicate detector "window" would still be intact after the long shut-down time.

Two days later, through the efforts of the experiment liason John Aiello and others at Goddard, we had the tape containing one satellite orbit, or about 90 minutes worth, of data from the SS Cyg pointing. We simply couldn't believe what we saw when we plotted the data: SS Cyg had large amplitude X-ray pulsations with a period of about 8.8 seconds!

The period was not regular either. First of all, it decreased slowly throughout the observation. Second, there were random glitches during which the period would quickly shift by up to one-tenth of a second. And third, the amplitude of the pulsations varied from nothing to about 50%.

The changing period ruled out the old hypothesis of a magnetic field as the cause of the oscillations, and the large amplitude of the X-ray pulsations — and their basic coherence — seemed to rule out blobs of matter circulating in the inner part of the accretion disk. The origin of the pulsations had to come from the region close to the white dwarf surface, but no one was quite sure what kind of instabilities would produce the large amplitude, basically coherent sinusoidal X-ray pulsations.

Since the A-2 low-energy detector had held up remarkably well for the pointing, we decided to try again — this time for U Gem. Then we waited.

In October there was a 3 week time when HEAO could do a pointing at U Gem. Janet Mattei marshaled many AAVSO members into keeping a constant watch on this star during October. And, on Oct. 13, U Gem started to rise.

There was panic in the Caltech HEAO-1 data room. It was almost the weekend. Few HEAO-1 operators would be on duty in the Goddard control room. It looked like the outburst would be short and not very bright, so we didn't have much time to schedule a pointing. But we did get one, and as it began — when all systems were go and there was no way to halt the observation — the variable star observers informed us that the star was at 10th magnitude and declining. We were afraid we'd waited too long.

The first indication that luck was with us came several hours later when we received a couple of minutes of data in real time during a satellite-to-ground station pass. From the large count rate we saw, it seemed U Gem was (still) a bright, soft X-ray source.

When we eventually received all the data, two things were immediately apparent: (1) there was no major modulation of the X-ray light with the orbital period of the systems and (2) half of the X-ray light was modulated with a 20 to 30 second "quasi-coherent" oscillation.

There had been evidence of pulsations of a quasi-periodic nature from data taken during a HEAO-1 pointing of AM Her in April 1978. When we looked closely, we found other similarities between SS Cyg, U Gem, and AM Her. All had shown, during some part of an outburst, weak, hard X-ray emission which could fit with a thermal bremsstrahlung spectrum, and all had intense, soft X-ray fluxes with a blackbody temperature of 250,000 Kelvin. The ratio of the soft to the hard X-ray flux was 1:10 for all three systems.

How were the soft and the hard X-ray fluxes related? Was the soft X-radiation due to reprocessing of the absorbed hard X-radiation? Would all cataclysmic variables which emitted soft X-rays turn out to be X-ray pulsators? What were the time scales of the pulsations telling us about the source of the oscillations? What was the behavior of the pulsations telling us about their nature?

While I've posed many questions, I haven't given any answers — only clues which are very difficult to interpret. And there remains much more data which must be analyzed before a complete scenario of cataclysmic variables can be attempted. What I've tried to do here is tell you about a few of the very special moments on HEAO-1, moments which many amateur astronomers shared with us.

The experimenters at all the HEAO-1 collaborating institutions are sincerely grateful for the data those observers provided, data now appearing in scientific publications with acknowledgements to the AAVSO and VSSNZ. For myself, it was a great thrill to work with these astronomers.

France Cordova
HEAO-1 Investigator
California Institute of Technology

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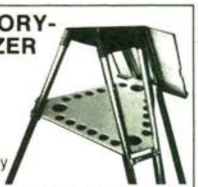

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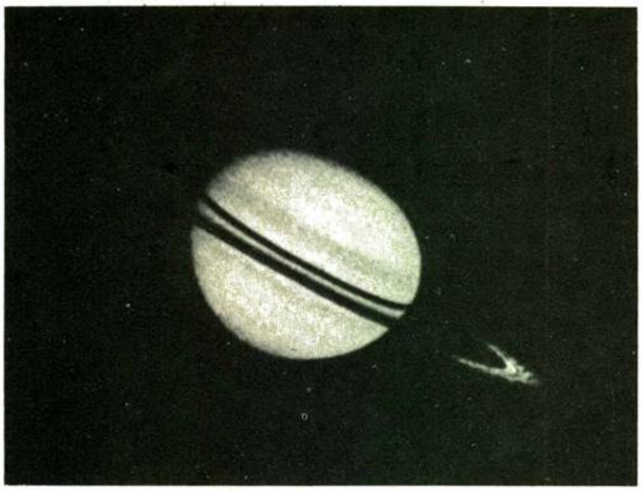
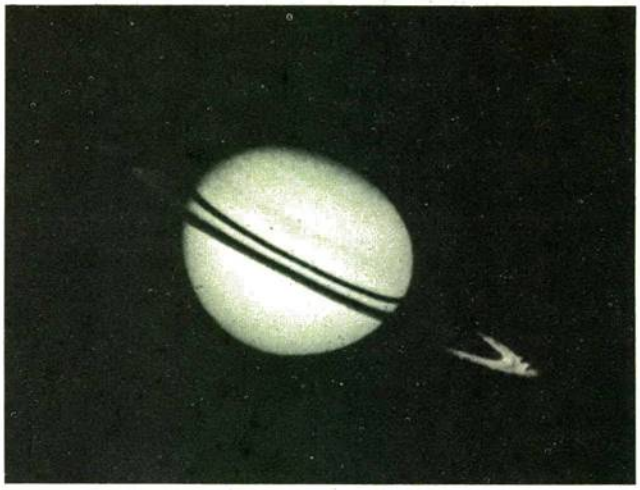


Saturn in red light



Saturn in blue light

More Pictures from Saturn

The photographs on this and the following pages were returned across nearly a billion miles of space. They have a compelling quality which transcends their immediate appearance. Never again will there be "first, close-up" photos of Saturn; a moment of history has passed.

But Pioneer 11 was much more than the first tentative probing of an alien world. The images and data represent a triumph for the engineers and managers who balanced a thousand-and-one conflicting demands in order to get them. These people, whose backs you see in the control room shots on TV, are often unnoticed: they publish no papers; their names are even less familiar than those of scientists. They are the "interface" between the scientist and the hunk of hardware at Saturn built to scratch an itchy human curiosity. And in this mission, as in many others, their job is to make it work.

What were Pioneer 11's difficulties? Was the mission in danger of failure?

Of course there was a small chance Pioneer 11 would be totally destroyed in crossing the ring plane. But the real difficulties and dangers concerned receiving the data, the reason for sending Pioneer out there in the first place.

P-11's time of arrival at Saturn turned out to be about the worst possible. The craft arrived when Saturn was close to conjunction with the Sun (in line with the Sun as seen from Earth), but this would not have imposed drastic constraints if the Sun's rise to maximum activity had not begun sooner than anticipated. As it happened, the signals from the craft passed through a noisy and flare-prone solar environment. This affected nearly every experiment aboard, but none more than the picture-taking.

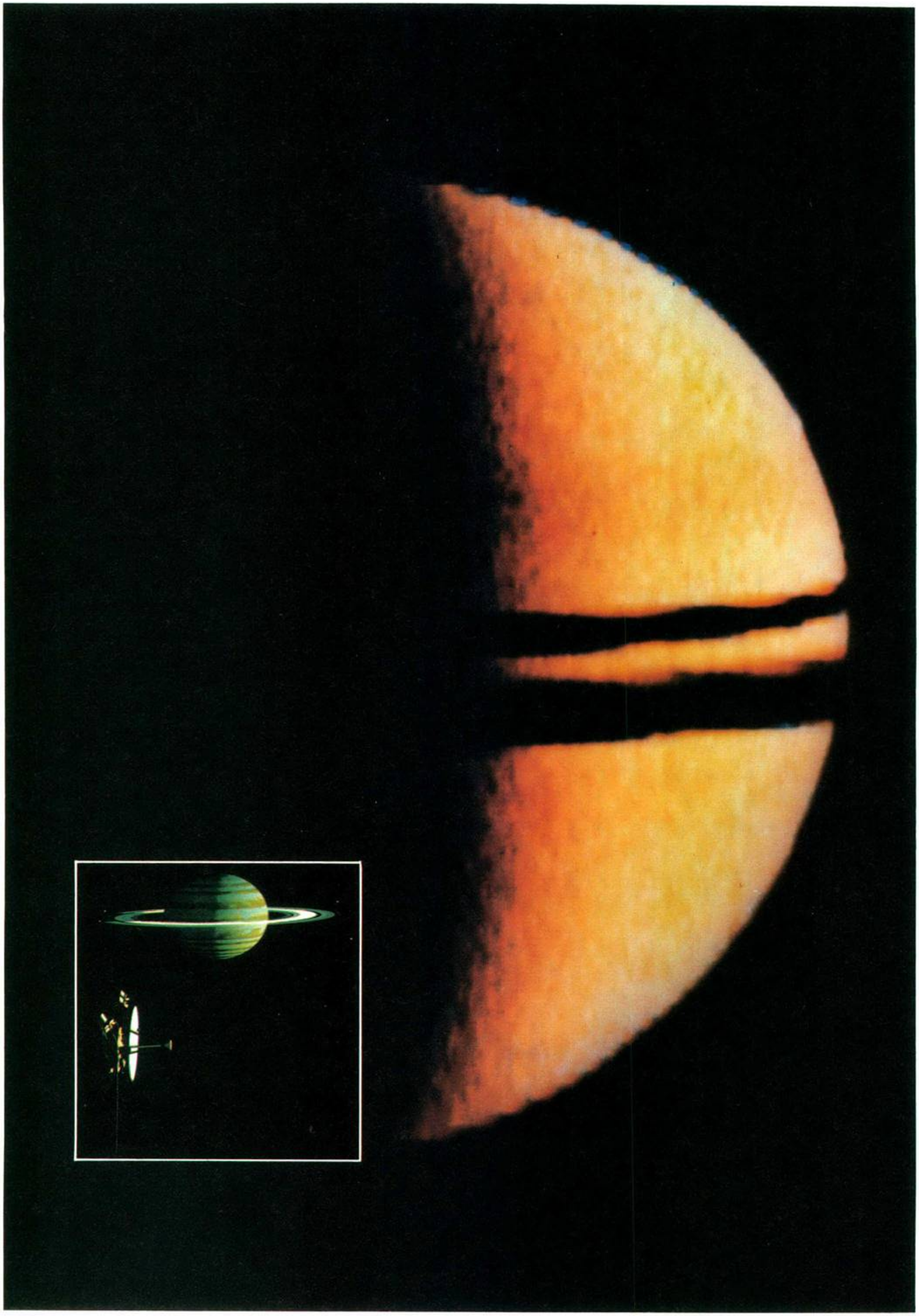
The Pioneer-11 spacecraft had a very limited capacity to store data onboard. Accordingly, as fast as it was generated by instruments, the data had to be radioed to Earth. The rate of transmission normally was 1024 bits (that is, dots and dashes) per second.

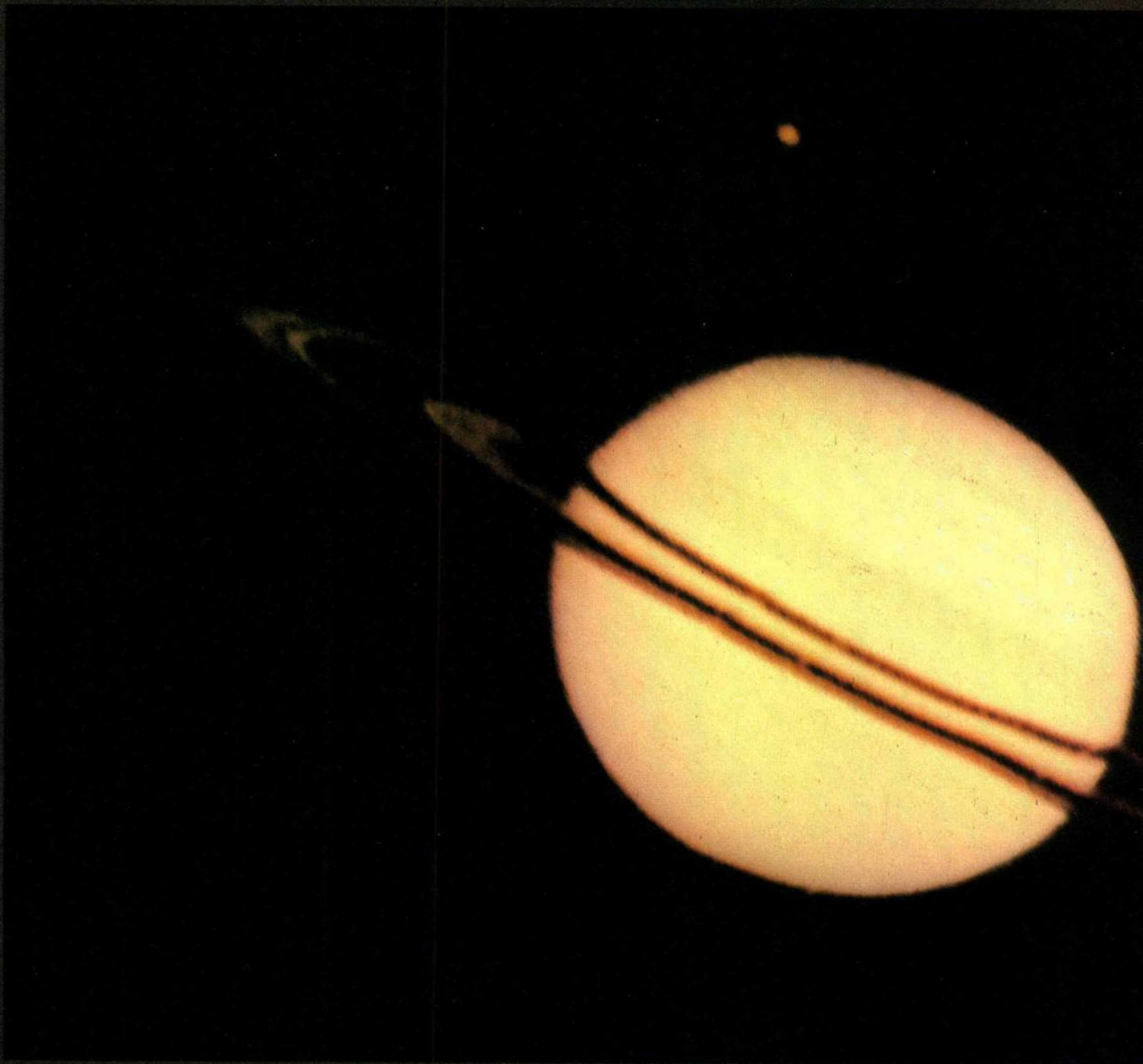
But from our point of view on Earth, we were trying to hear a little signal amidst the mighty roar of noise from the Sun. The solution? Cut the bit rate down to 512 per second. Then each "dot" or "dash" could be received twice as long — with an improved chance of proper reception. But this meant that half the data must be left out. As the P-11 flyby occurred, the data rate was dropped again to 256 bps, then 128, then 64. What got dropped? — and who decided? That was the role of the Project Manager — and with Pioneer 11 the most expendable data were the pictures.

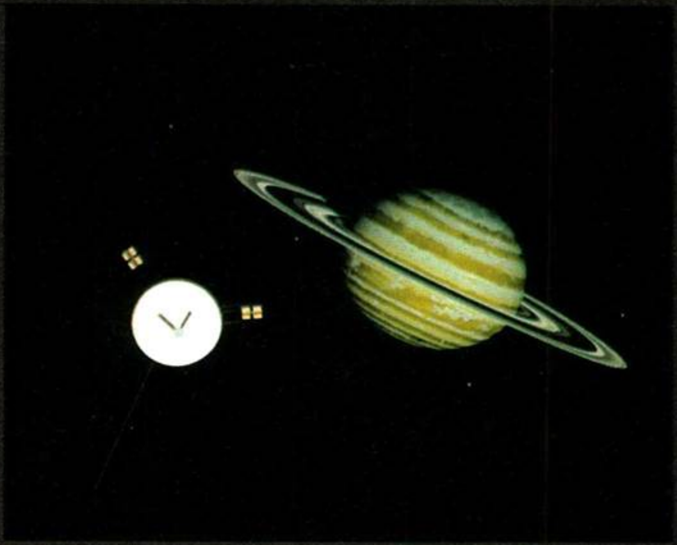
It wasn't necessary to shut the spin-scan imager off entirely. Instead, the device was turned on for a shorter and shorter time each roll, and its scans forward and back were decreased in extent. In visual terms, the viewing "window" got smaller and smaller. And why not? After all, most of each scan is black, empty space. The difficulties lay in choosing when to have the scanner on — the wrong moment could mean missing the planet altogether. And that choice had to be made over an hour before each picture was taken.

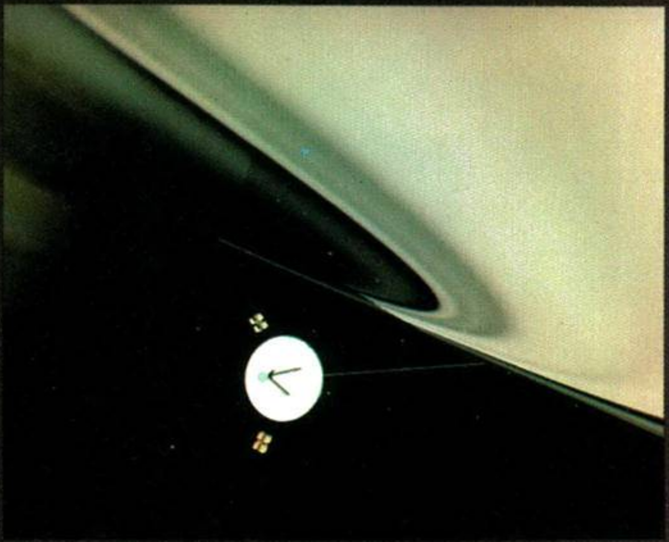
If the exact trajectory of the craft is uncertain (as it was) and if you, as a scientist, want your images, then you do a lot of quick thinking and high-quality hoping. The tough decision to obtain the pictures of Titan illustrates this beautifully. When the time came to hunt for the moon, the bit rate was

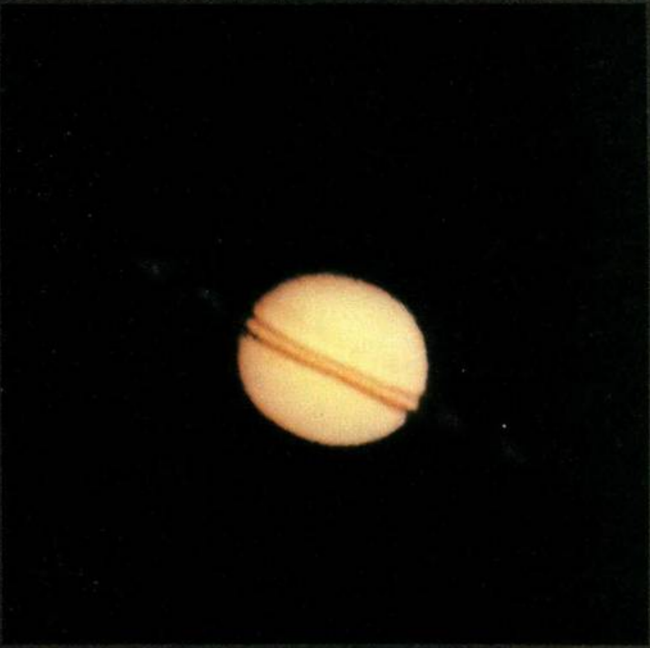
Right: Saturn as never before seen: a crescent planet lit by the distant Sun. On its outbound course, Pioneer glanced back to take this photo showing the shadow of the rings (upper dark line) and the backlit rings themselves (lower dark line). Inset: A computer simulation shows the spacecraft looking back at Saturn. All simulations by Computer Graphics Lab, JPL.

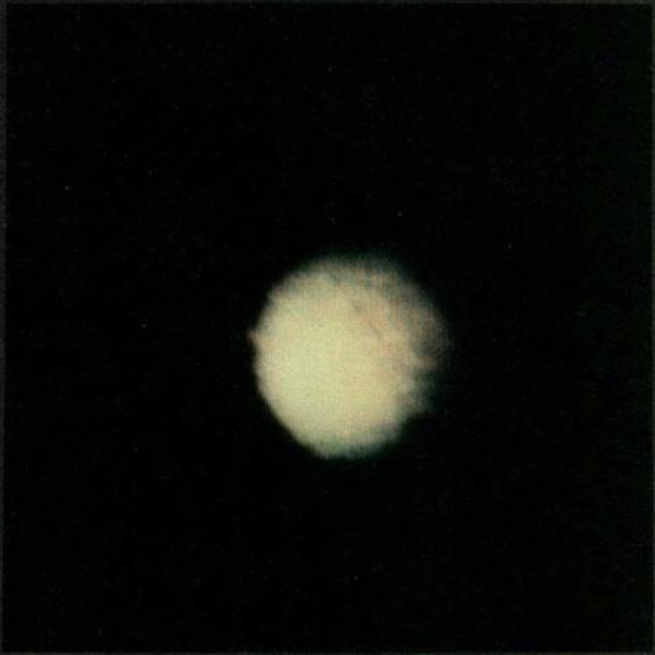




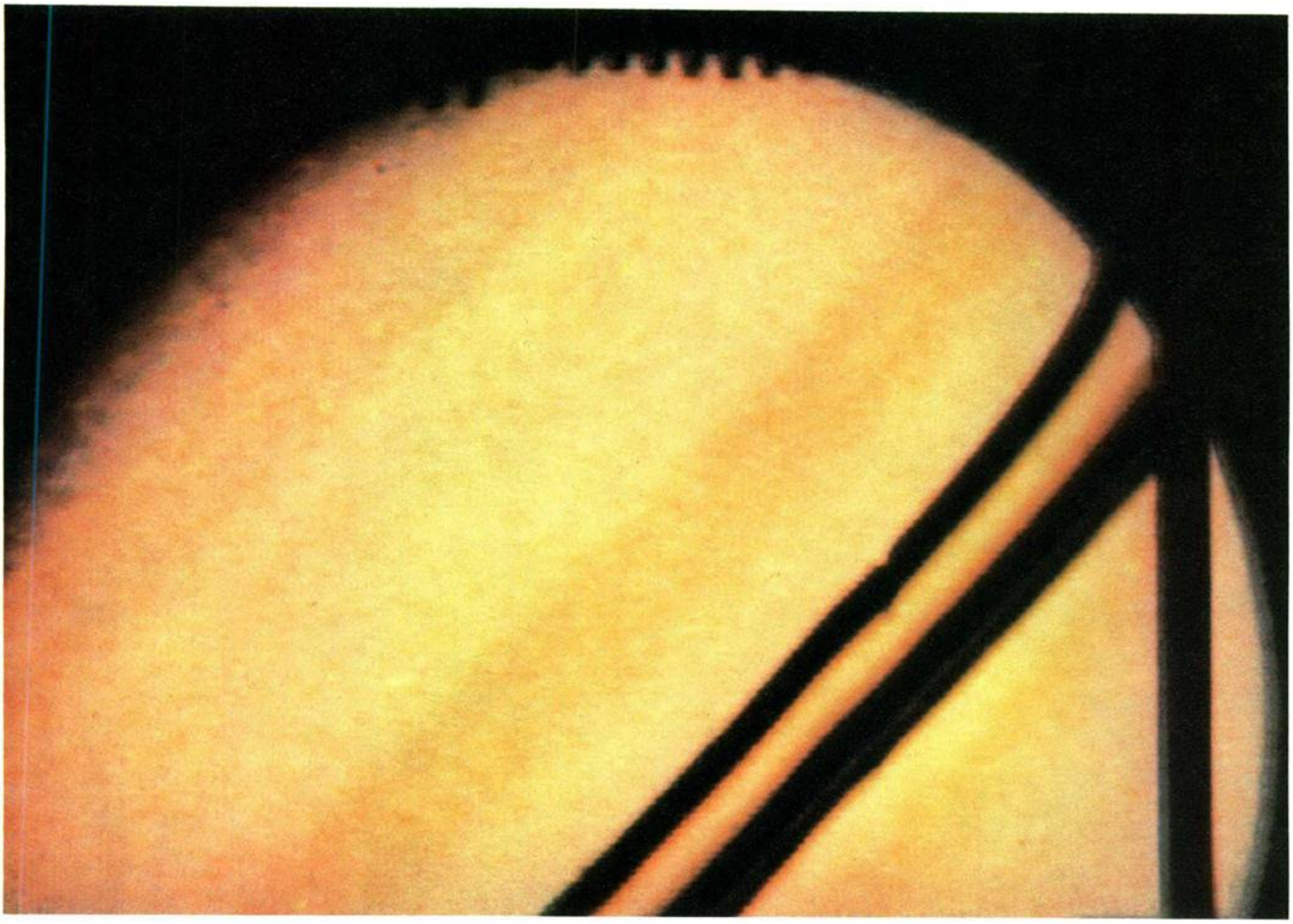


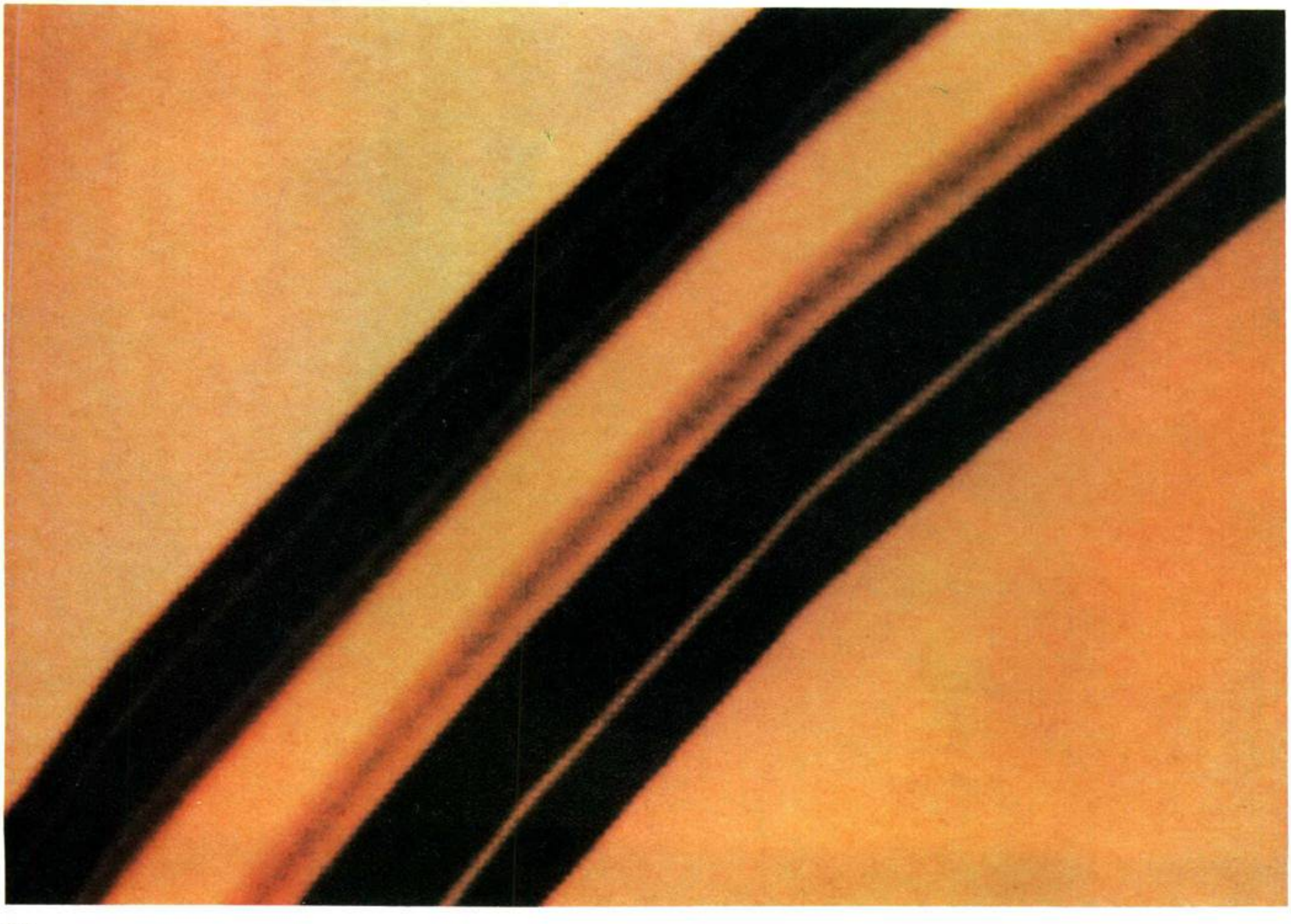


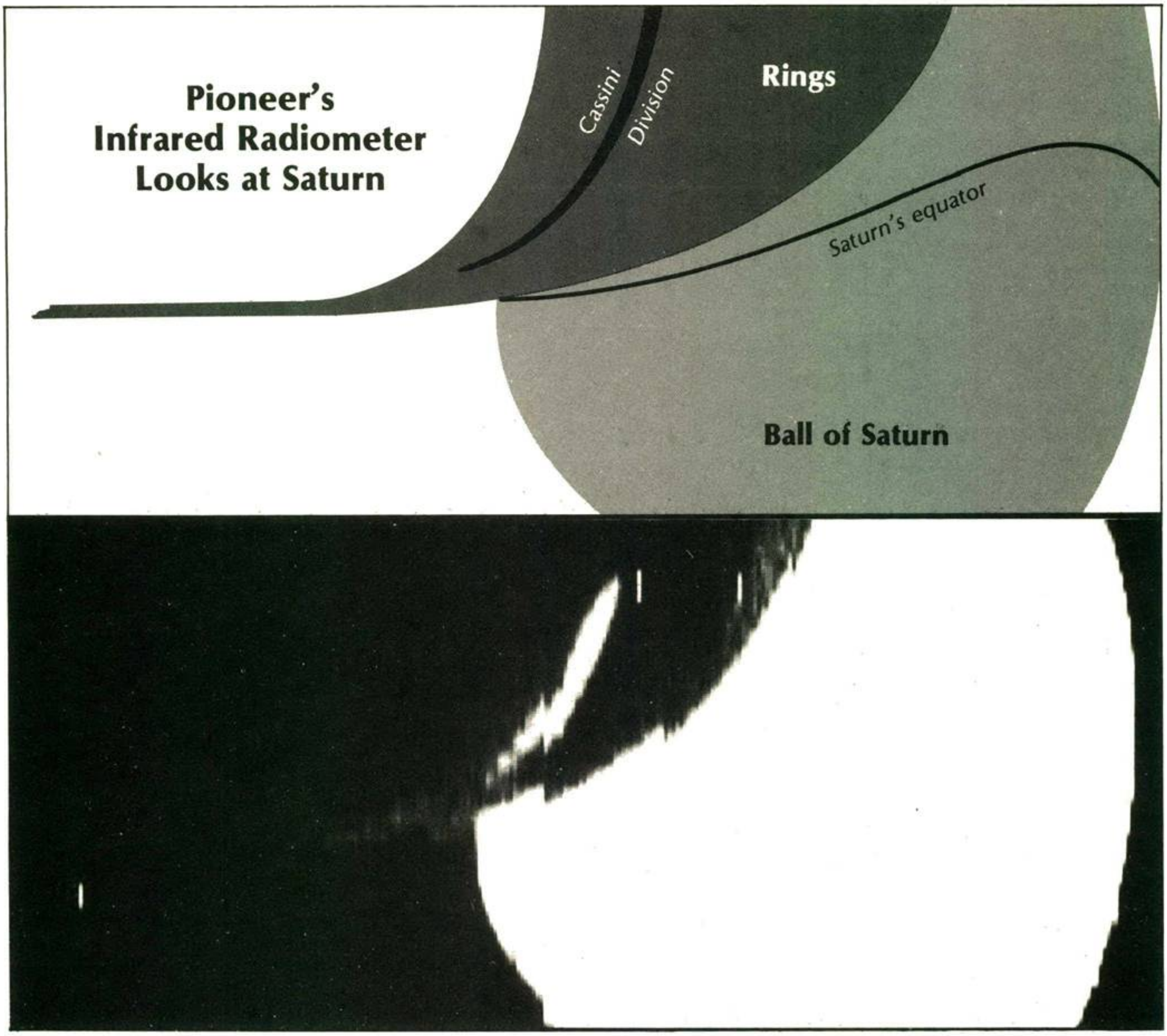




Upper left: The strange sight of Saturn's ball surrounded by weird-looking rings. Backlit, the familiar rings take on a very different appearance. Bottom left: Three computer simulations show what you might have seen if you could tag along with Pioneer: approaching the planet, racing under the rings towards closest approach, and popping out from behind Saturn as Sun and Earth reappear. Above top: Compare the coarse detail of this first far-encounter shot with the later one at left. Above: Titan's best likeness so far.







Left above: A million and a half kilometers out, Saturn overflows the image area. Left below: Closer still, only portions of the disk and rings fit in the field of view. Above: The heat-sensing scanner's fixed angle of view distorts Saturn and the rings wildly as the spacecraft flies through the system. The key drawing shows what's what; the actual data are shown below. Photo courtesy of Andrew Ingersoll, Caltech.

Photo Data

Page	Date	Range (miles)	Picture #
30 (L)	Aug. 29	1,600,000	9107
31	Sept. 2	529,000	9129
32-33	Aug. 29	1,760,000	9105
33 (T)	Aug. 22	5,180,000	9101
33 (B)	Sept. 2	230,000	9059
34 (T)	Aug. 31	971,000	9118
34 (B)	Sept. 1	309,000	9119

(All photo numbers have "A79-" as a prefix.)

so low the window's size was only a few degrees of roll. It was possible that Titan would be missed entirely — and there was time for 5 images, no more. The planning, skill, and luck paid off, for all but the very first had Titan completely in the frame.

Our long series of successes and salvaged near-disasters in solar system exploration have tended to blunt our appreciation of them. The drama seems trumped up at times. Yet it isn't. A few powerful solar flares at the wrong time or a malfunctioning explosive bolt can wipe out years of work for an experimenter — or force everyone involved to scramble around salvaging what they can.

There are no assured successes, only years of hard work and fussing over details: Neither Viking landed on a rock. Neil Armstrong had enough gas to fly Eagle over a boulder field. Someone clever realized that Mariner 10 could get three passes by Mercury. Skylab lost its sunshield and half of its solar power panels, but the mission succeeded. And Pioneer 11 gave us our first good look at Saturn.

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Mars Overtakes Jupiter

As dusk falls on these chill December evenings, Orion is coming over the eastern horizon, heralded by the Pleiades and Hyades star clusters. High overhead swings the Great Square of Pegasus and our companion-galaxy, M-31, in Andromeda. The Milky Way still crosses the sky, but its most brilliant extent is now low in the west, where Cygnus is resembling either a nose-diving swan or an upright cross, according to how you look at it.

At no other season do you get such a fine view of celestial glories, past and future. Summer is visibly setting in the west, while winter lies in sight to the east. In June, you miss seeing Orion set as Lyra rises because of the long hours of daylight and late sunsets. By nightfall, Orion has gone and Lyra is well up in the northeast.

January Previews

2	Full moon
3	Earth at perihelion
6	Mercury at aphelion Moon near Regulus
7	Moon-Jupiter conjunction Moon near Mars
8	Moon near Saturn
10	Last quarter moon
13	Juno (asteroid) at opposition Moon 5° north of Uranus Moon 4° north of Neptune
17	New moon
20	Moon near Venus
21	Mercury at superior conjunction
24	First quarter moon
27	Occultation of Aldebaran

The current track of the Moon through the sky lies close to the ecliptic, thus producing a long run of occultations and conjunctions with planets and the few bright stars (like Aldebaran and Regulus) that lie near it. This gives you many impressive and striking alignments to watch for and photograph.

Tonight, sandwiched neatly between the summer and winter halves of the Milky Way, you'll find the "watery" fall constellations. Here, too, runs the sky's prime meridian, the vernal equinox, whose slow, westward slide along the ecliptic is moving the constellations through the year.

The December sky seems to have been arranged for your convenience, with the stellar wonders displayed during the early evening hours. (Of course, if Cancer, Leo, or Hydra is your favorite group, you'll be out later.)

But pity December's poor planet watcher! Apart from Venus (visible just after sundown), the three bright planets — Mars, Jupiter, and Saturn — won't be rising until midnight, and an hour or so more must pass until they're high enough to clear the horizon haze. Worse yet, several other fine events this month, like the conjunction of the Moon and Saturn, also take place in the wee hours. What's to be done, then? Stifle those sighs, bundle up, and head out there! You think it's cold now? Wait till February...

Mercury

As the month opens, Mercury is about a week past the time when it lay between Earth and Sun. Mercury is now moving rapidly to the west (right) of the Sun, and because of this, you'll catch sight of it rising before the Sun does.

On page 42 there's a diagram showing Mercury's path in the southeastern sky. The azimuth (direction) and altitude are shown in degrees (0° = north, 90° = east, 180° = south, & 270° = west). The positions in the diagram are for 45 minutes before sunrise.

The easiest way to locate this elusive planet is to scan the area with binoculars or a wide-field finder scope. Then having located it, you can use your telescope's powers to zero in on the planet's ball. But don't expect too much. Use only enough power to see the shape clearly — no more, for the long optical path of the planet's light through the Earth's atmosphere guarantees a fuzzy and moving image, and using high powers just magnifies these distortions.

Venus

Above the Mercury diagram on page 42 is a similar one for Venus, but over a longer time span. The diagram shows Venus' positions 45 minutes after sunset.

Because Venus orbits the Sun farther out than Mercury, its apparent separation from the Sun can become far greater. This means its loop in the sky is larger, higher, and sweeps over a bigger part of the horizon. Though low at present, Venus' radiance is unmistakable, and it will become even more prominent as winter and spring progress.

For the first half of December, Venus won't be any higher than Mercury is in the morning sky, but after the middle of the month, will be moving almost directly up, away from the horizon. Observers with telescopes will see a -3.4 magnitude ball of featureless white swimming in murky air, its 12 arc-second disk looking almost round. Over the months to come, the out-of-roundness will slowly increase along with the apparent size.

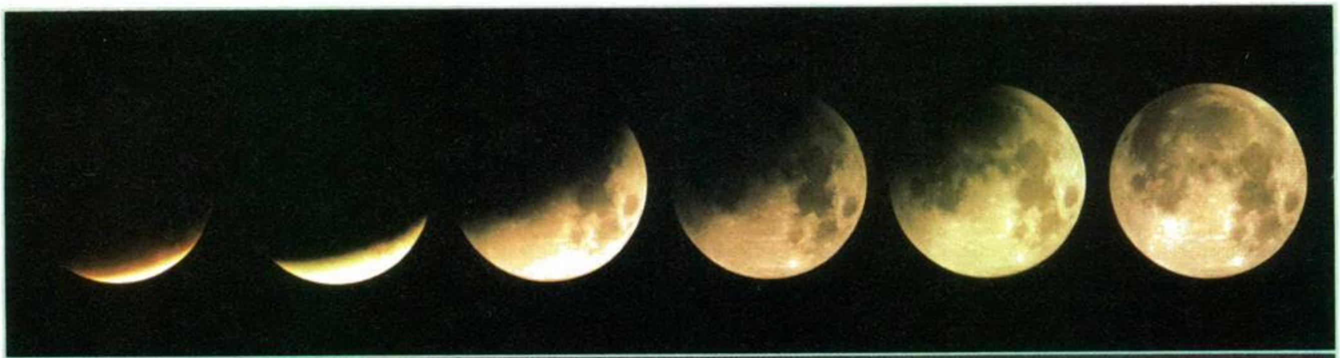
Earth

On Saturday the 22nd, at 11:10 UT, the Sun will reach its farthest southern declination (being overhead in latitude 23° 26′ 18″ south), and winter for the northern hemisphere will officially begin.

Moon

The Moon's orbital path around the Earth will take it near to several planets this month. These close approaches, called conjunctions, are fun to watch (and easy to photograph, too). Your "equipment" can range from naked eye up to a telescope, but in general a field of view like that in binoculars is more impressive in overall effect.

A nearly full moon will lie in the vicinity of the Pleiades, a bright star cluster in the constellation Taurus, on the night of the 2nd-3rd, and near Aldebaran, a first magnitude star in

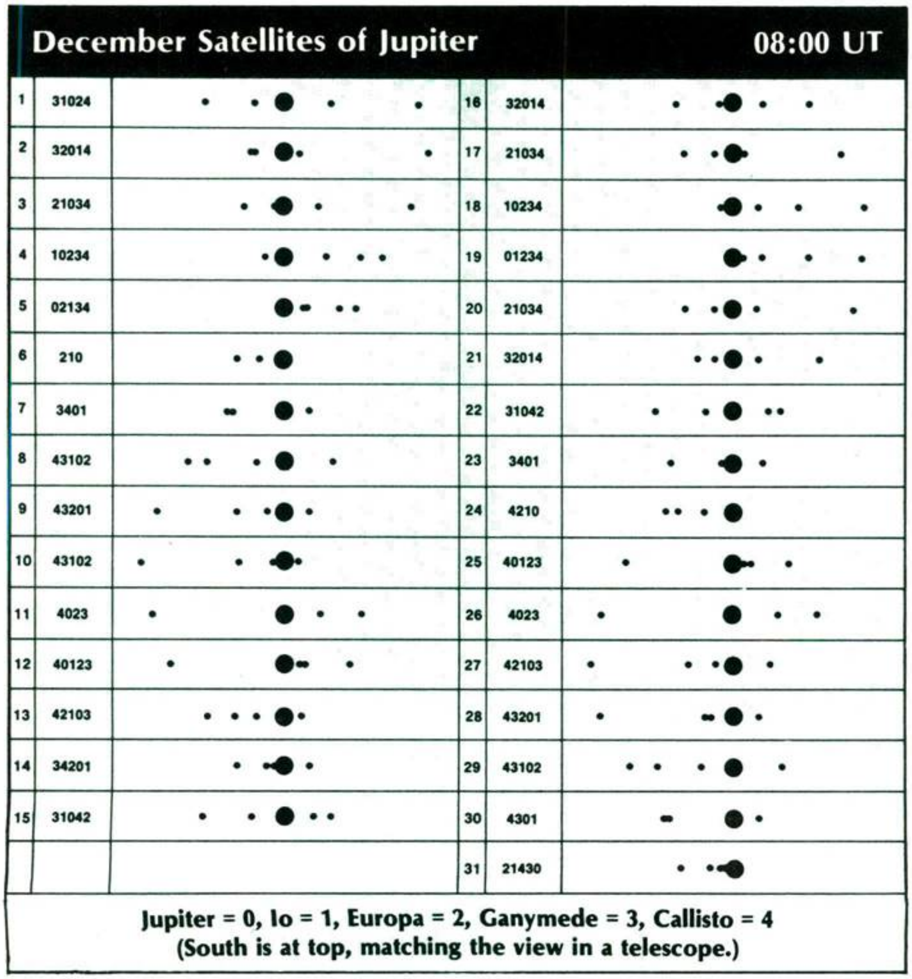


The Lunar Eclipse

On September 6th, the Moon moved wholly into the shadow of the Earth, which resulted in a total lunar eclipse. The event was best seen from the western half of the continent, because there the entire eclipse was visible before the Moon set. But most everyone had a good time, all in all.

Top: James Fanson made a multiple print of several slide exposures taken with a 1250 mm f/10 Cassegrain scope from Waukesha, Wisconsin. Right: Steven Wissler, of Pasadena, California, used an 8" f/8 Newtonian and 200 ASA slide film to get a photo that records the inky blackness of the Earth's shadow. Below: Pat Michaud exposed his film long enough (12 seconds) to show a coppery moon. The telescope was a 14¾" f/4.6; the location: Yucaipa, California.

With solar activity climbing towards maximum, aurorae are becoming more and more common: whenever you step outside at night, take a look north just to see if anything's brewing. Photo taken by Doug Stewart in Ottawa, Ontario. Film was 64 ASA and exposure 30 seconds.



December Satellites of Jupiter **08:00 UT**

1	31024	16	32014
2	32014	17	21034
3	21034	18	10234
4	10234	19	01234
5	02134	20	21034
6	210	21	32014
7	3401	22	31042
8	43102	23	3401
9	43201	24	4210
10	43102	25	40123
11	4023	26	4023
12	40123	27	42103
13	42103	28	43201
14	34201	29	43102
15	31042	30	4301
		31	21430

Jupiter = 0, Io = 1, Europa = 2, Ganymede = 3, Callisto = 4
(South is at top, matching the view in a telescope.)

the same constellation, on the following night.

When the Moon is near last quarter on the 10th, 11th, and 12th, it will pass by Mars, Jupiter, and Saturn, respectively. The morning of the 17th, look for a waning crescent moon 6° above Mercury in the morning sky, and on the evening of the 21st, Venus will be about 8° below a waxing crescent moon.

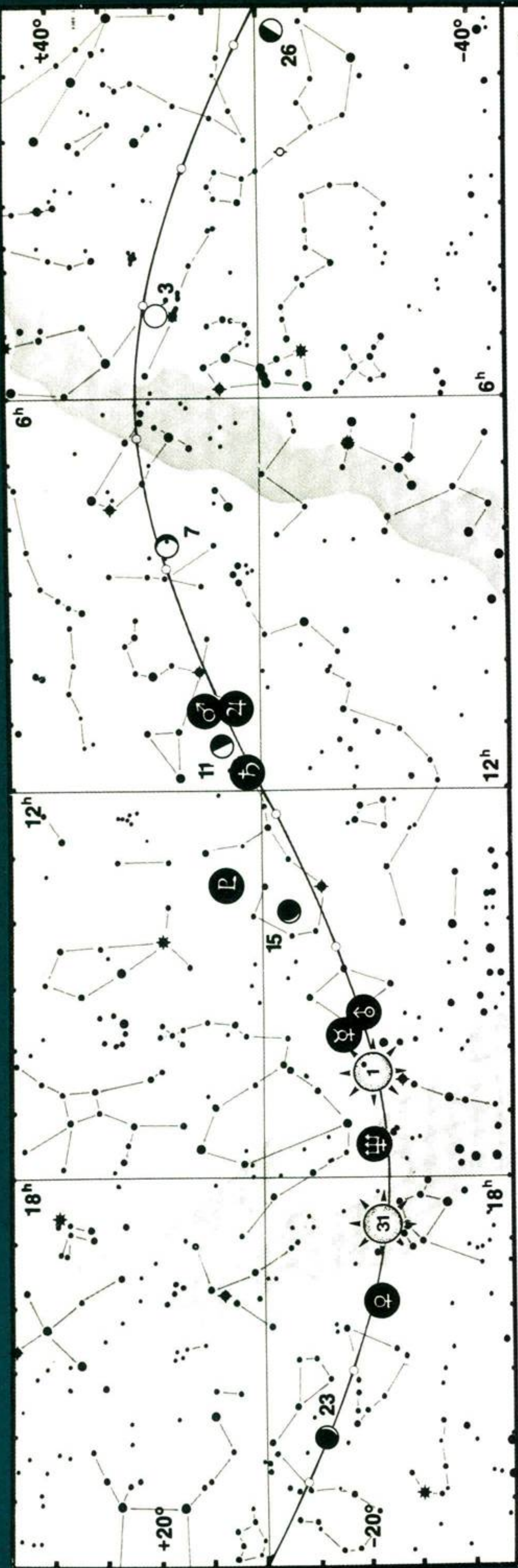
The part of the U.S. lying to the southeast of a line between western Oklahoma and Chicago, together with the Eastern Townships of Quebec and the Canadian maritime provinces, will see an occultation of Aldebaran during the late afternoon and evening of December 30th. The Moon, 11+ days old, will approach Aldebaran from the west, the disappearance happening on the Moon's dark limb. However, because many observers will have to settle for watching the event in twilit skies, this occultation won't be as dramatic as some recent ones have been.

Mars & Jupiter

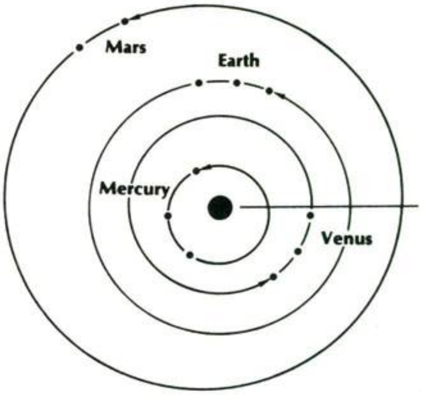
These two planets belong together

Planet Finder

December 1979

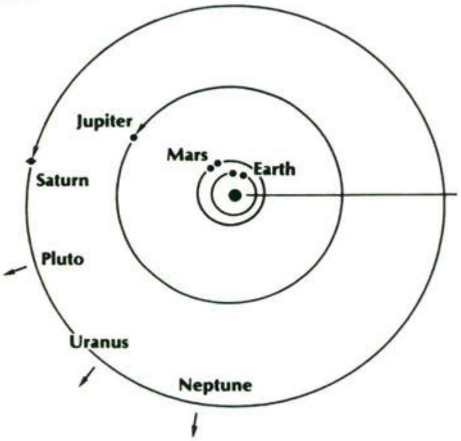

+40°
-40°
26
3
6h
6h
7
11
12h
12h
15
1
31
18h
18h
23
+20°
-20°

The Planets in Their Courses


Mars
Earth
Mercury
Venus

The positions of Mercury, Venus, Earth, and Mars in their orbits are shown for the beginning, middle, and end of the month. (Mars for the beginning and end only.) The vernal equinox is the line at right.

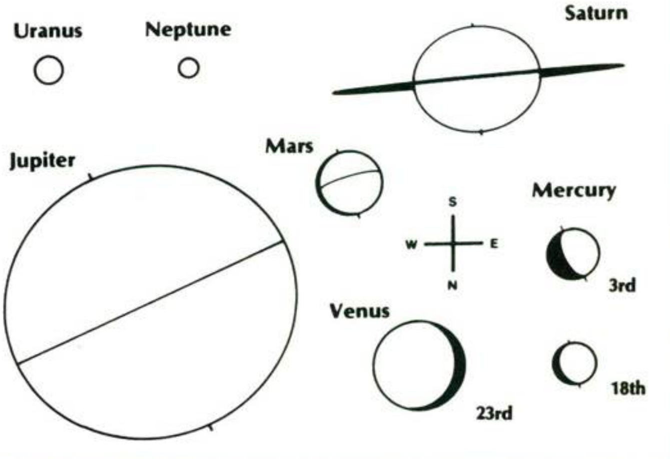
The orbits of Earth, Mars, Jupiter and Saturn are shown at right. Earth and Mars' positions are for the first and last of the month; Jupiter and Saturn for midmonth. The outermost planets' directions are indicated.

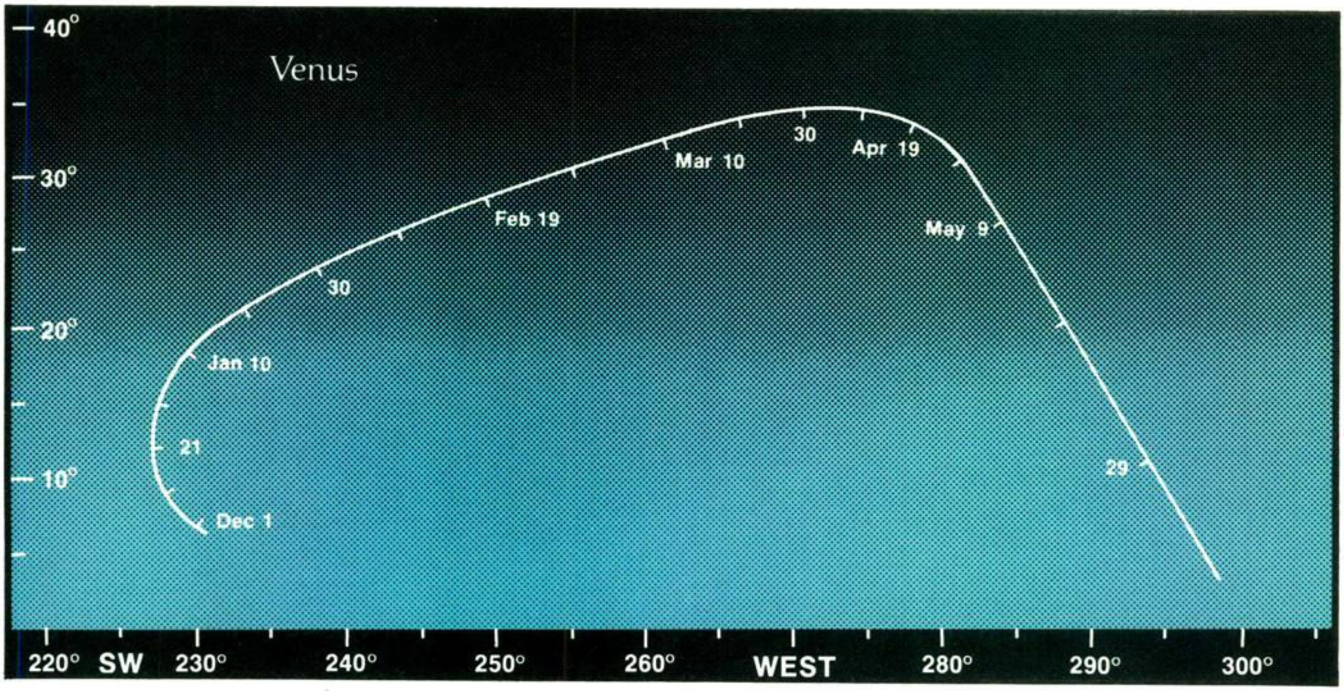

Jupiter
Mars
Earth
Saturn
Pluto
Uranus
Neptune

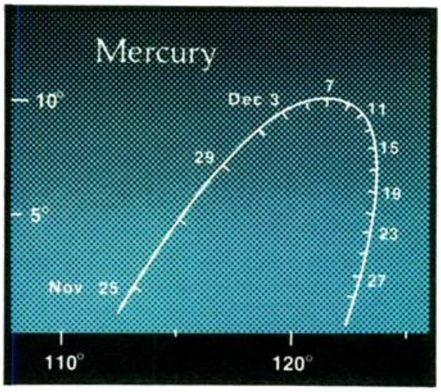
Positional Data

Planet	Date	R.A. (1980.0)	Dec.	Mag.	Distance (AU) from Earth	Distance (AU) from Sun
Mercury	☿ 10	$15^h40.4^m$	−17°24.7′	−0.3	1.06	0.37
	20	$16^h34.5^m$	−21°05.6′	−0.4	1.25	0.43
	30	$17^h37.8^m$	−23°41.7′	−0.4	1.36	0.46
Venus	♀ 10	$19^h02.2^m$	−24°13.4′	−3.4	1.45	0.73
	30	$20^h47.5^m$	−19°45.9′	−3.4	1.36	0.73
Mars	♂ 15	$10^h49.3^m$	10°20.3′	+0.6	1.12	1.64
Jupiter	♃ 15	$10^h47.8^m$	8°46.9′	−1.7	5.08	5.38
Saturn	♄ 15	$11^h50.6^m$	3°17.1′	+1.2	9.43	9.42
Uranus	⛢ 15	$15^h23.3^m$	−18°17.4′	6.1	19.58	18.72
Neptune	♆ 15	$17^h18.2^m$	−21°44.9′	8.0	31.26	30.28
Pluto	♇ 15	$13^h42.4^m$	7°30.9′	14.0	30.63	30.19

Telescope View


Uranus
Neptune
Saturn
Jupiter
Mars
S
W
E
N
Mercury
3rd
Venus
18th
23rd





Above is the path Venus will take in the months to come, while to the left is a similar diagram for Mercury. Both are for an observer at 40° north latitude, and the time is 45 minutes after sunset (for Venus) and 45 minutes prior to sunrise (Mercury).

Universal Time

Astronomers the world over use an unambiguous system of time reckoning based on a 24 hour clock, called Universal Time (UT). Times given in Sky Almanac are in UT unless noted otherwise. To convert UT into your local standard time, subtract the following number of hours for each time zone: EST, 5; CST, 6; MST, 7; PST, 8; Alaska and Hawaii, 10. For example, if an event is to happen at 03:00 UT on Jan. 2, then the time in EST would be 10 p.m. Jan. 1. Likewise, 03:00 UT on March 5 becomes, in PST, 7 p.m. on March 4.

Lunar Phases

Full moon: Dec. 3rd at 18:08 UT, in Taurus. Last quarter: Dec. 11th at 13:59 UT, in Leo. New moon: Dec. 19th at 08:23 UT, in Sagittarius. First quarter: Dec. 26th at 05:11 UT, in Pisces. Apogee: Dec. 11th at 11h UT; perigee: Dec. 23rd at 16h UT.

here, for so you'll find them in the sky. Over the course of the last few months, Mars has been sweeping steadily eastward: from Taurus and Gemini through Cancer into Leo. During this time, Jupiter has been slowly moving eastward in Leo as well. On the 13th, ruddy Mars finally overtakes giant Jupiter, passing a little more than a degree and a half north of it.

The time of conjunction comes around midday on the 13th, so we'll have to be content with the view during the hours of darkness before or after the event.

You'll particularly enjoy hopping back and forth between them, noting how small Mars appears next to Jupiter, despite it's being over 4½ times closer. Your best bet is to use medium powers.

Jupiter will be an oval disk 38.6 seconds of arc wide at its equator, Mars only 8.3 arc-seconds. Their magnitudes will be -1.7 and +0.6, respectively.

Saturn

Saturn has moved from Leo into neighboring Virgo, and lies somewhat to the east of Jupiter and Mars, rising about an hour after them. On the 15th, Saturn's ball will be 17.7 seconds of arc wide, and its magnitude +1.2.

Currently, the Earth and Sun are on opposite sides of Saturn's rings, which are themselves almost edge-on to the Earth. To an observer, this means that unless you have a large telescope, you'll be seeing nothing of the rings but their shadow on the planet.

Uranus

Uranus isn't going to be easy to find this month, especially during the first two weeks. On the morning of the 5th, the magnitude 7.8 planet (diameter: 3.6 arc-seconds) is just to the east of the 6th magnitude star 28 Librae, but because both objects are only at an elevation of 9° (45 mintues before sunrise), they'll be very hard to spot. Their azimuth is 123°, and Mercury will be a few degrees to their upper left.

Neptune

In conjunction with the Sun on the 12th, Neptune spends all December in the glare of the Sun. Try hunting for it in January.

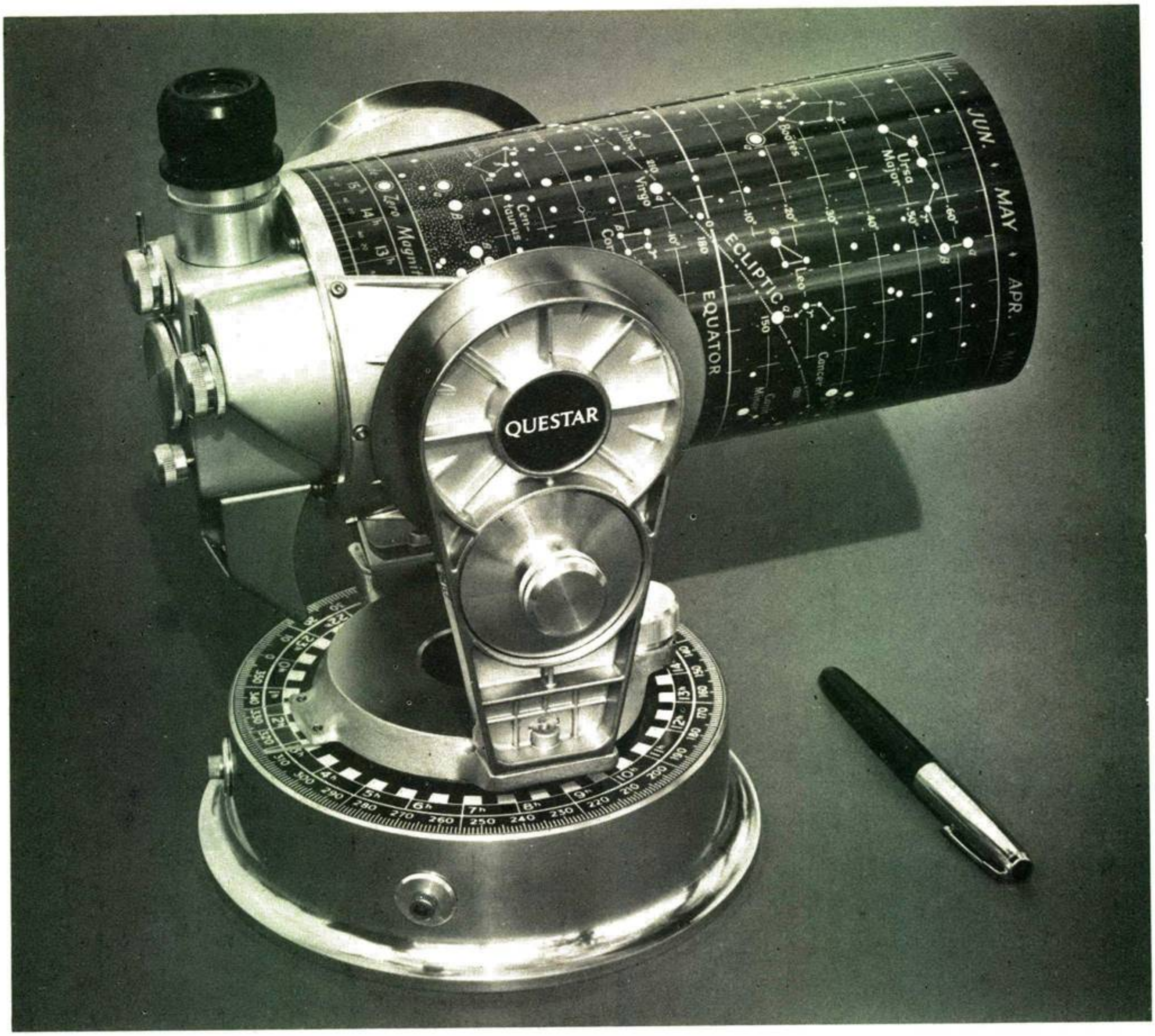
Meteors

Two showers tempt the hardy meteor observer in December: the Geminids (whose activity peaks around midday on the 14th) and the Ursids (peaking in the afternoon of the 22nd).

The Geminids are a relatively strong shower (about 50 per hour) and they are bright. Their radiant point on the sky lies northwest of the star Castor. Since the time of peak activity comes during daylight for North America, you'll have to observe on the morning of the 14th or the 15th.

The Ursids are a lot weaker, having some 15 per hour. The radiant is near Kochab, the brightest star of the Little Dipper. Again, the peak comes during daylight in North America, and so try on the night previous or the one following.

For both showers, the Moon will be no hinderance, since its phase for the Geminids is 4 days before new and for the Ursids, 3 days after new.



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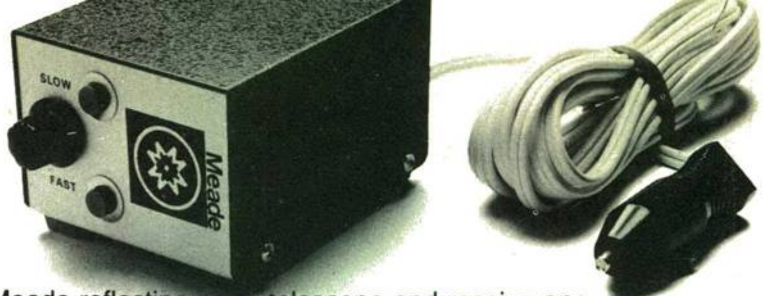

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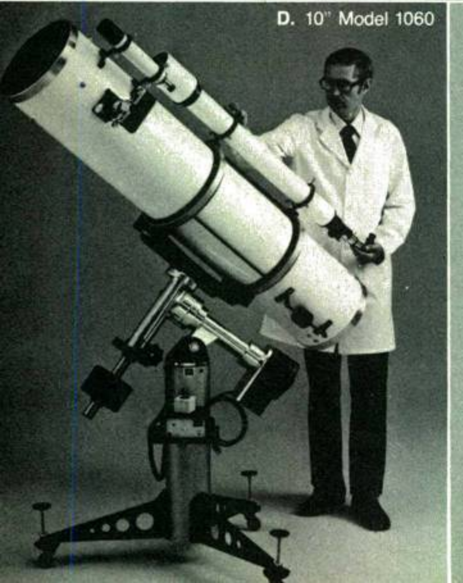

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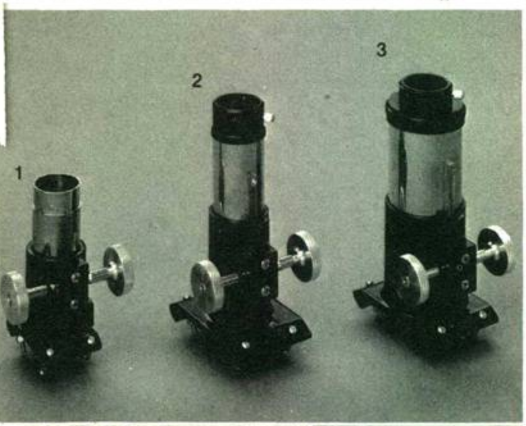

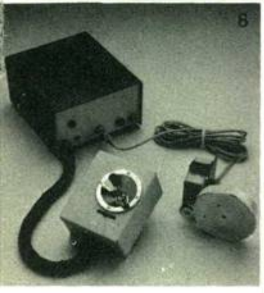

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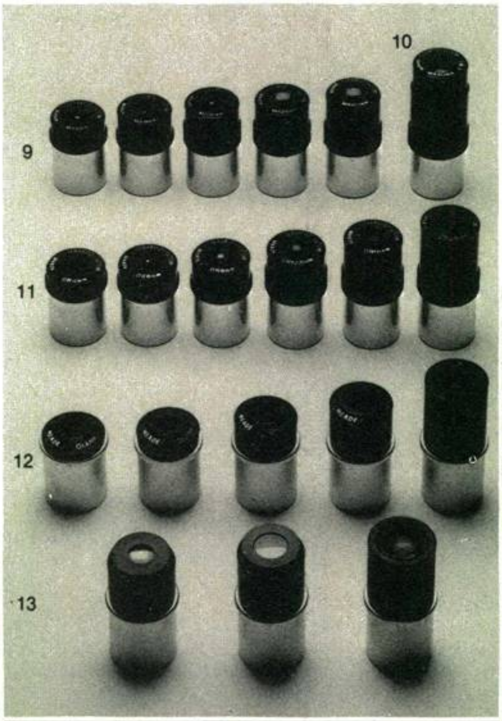

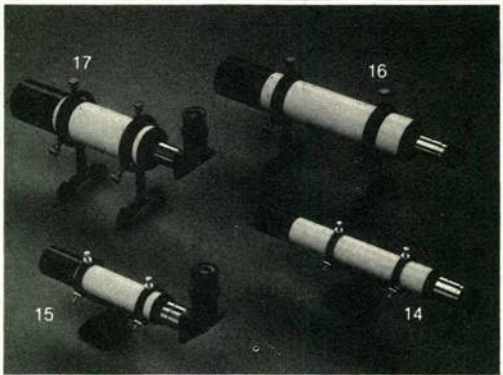

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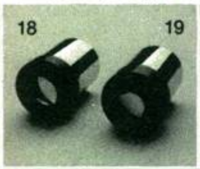

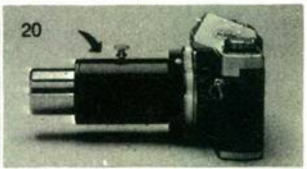

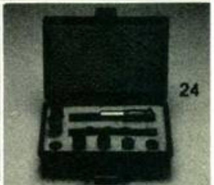

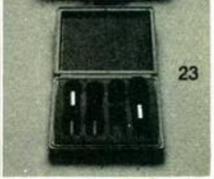

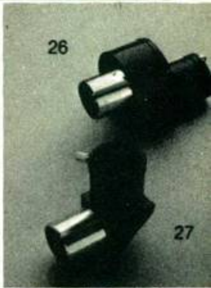

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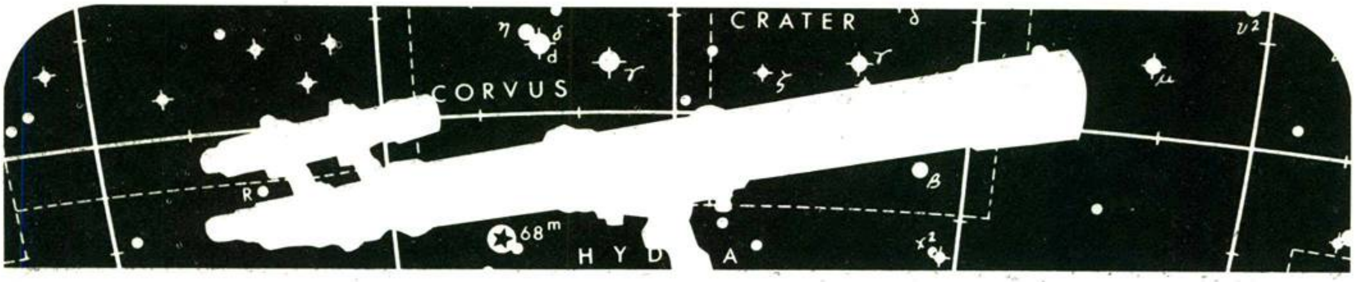


EQUIPMENT
ATLAS

Equipment for Observing the Sun

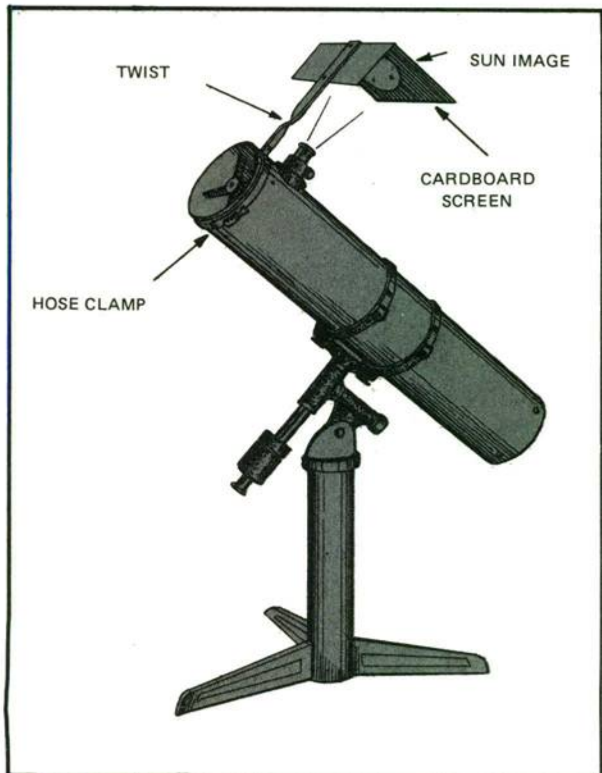
Long ago the Sun was more an object of veneration and worship than an object for observation and study. The solar disk, regarded as pure, perfect, and unblemished, became a divine symbol even in places where the Sun itself was not seen as a god.

We know now of course that the solar disk we see in the sky is far from being a perfect unmarked circle of light. Instead, observation of the Sun reveals a wealth of complex structure and activity, ranging from the familiar sunspots easily visible with the smallest telescope (and sometimes even with the naked eye) to more subtle features such as faculae and prominences.

Solar activity has long been known to vary over an approximate eleven year cycle, with the incidence of sunspots, flares, and other phenomena rising to a maximum level and then declining. One of these maxima is due early next year. Moreover, 1980 promises to be an especially exciting time for solar observing, for the Sun is expected to reach an extremely high level of activity during its maximum. Scientists have found that some of these periods of maximum activity are greater than others, but they don't yet understand why — in fact, the actual cause of the cycle itself is not yet fully understood. But a number of factors presently indicate that the coming solar maximum will be one of the highest of this century.

Now's the Time...

Are you ready to observe the Sun during the coming months of high activity? Remember, you can't simply haul out your telescope and look at the Sun as you would the Moon. A telescope alone isn't enough to view these features. You must use special equipment and techniques to convert your telescope — designed, after all, for observation of objects in the night sky — into a solar instrument. And remember, in observing the Sun you are, quite literally, playing with fire, and a good deal of care and caution is necessary (see box on page 48).



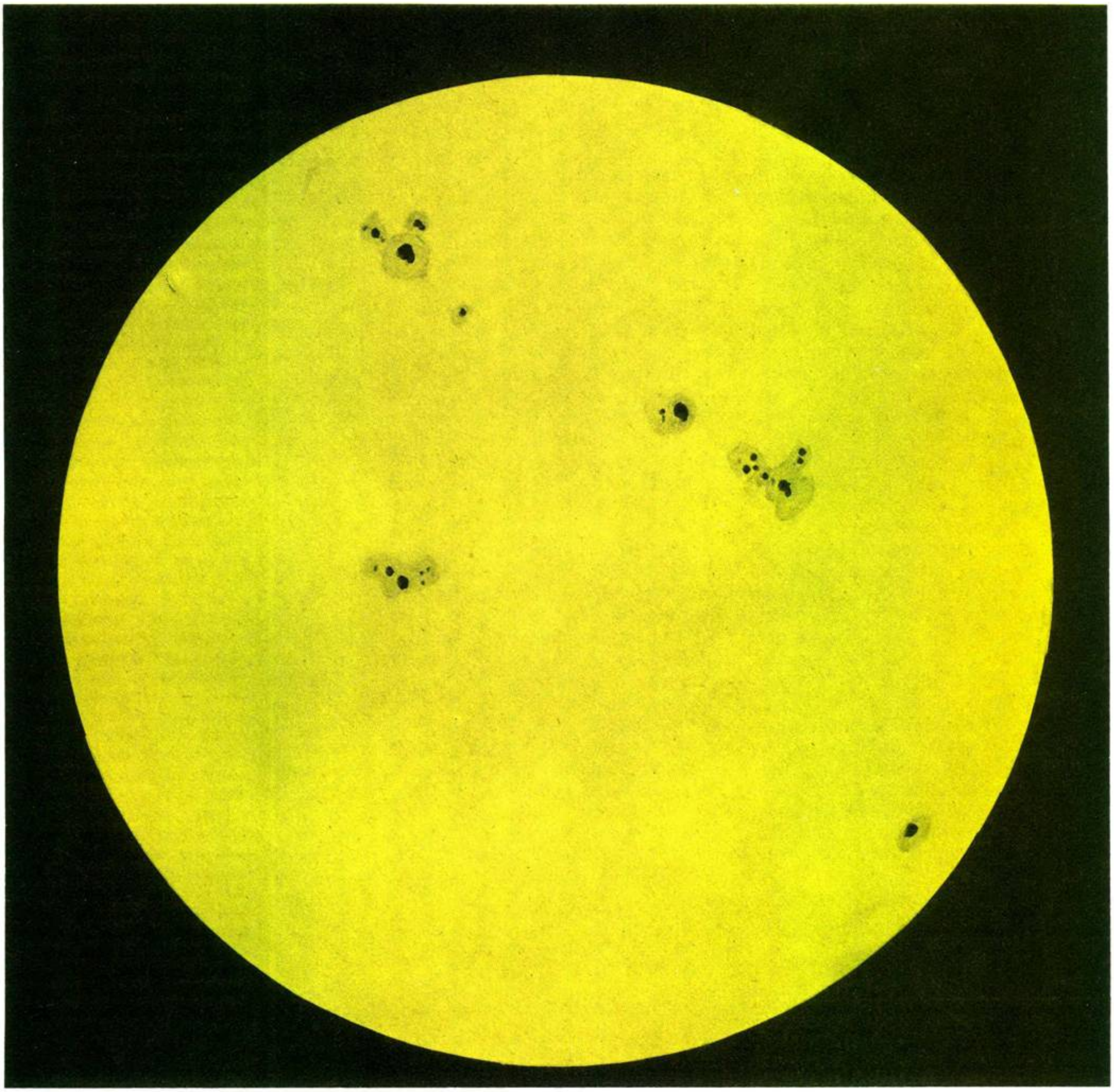
You can equip your telescope for solar observations with this easy-to-make solar image projection screen. Be sure to experiment first with a hand-held screen to determine the optimum eyepiece-to-screen distance, and make sure that you provide a large enough screen to include the whole solar disk. Note that the telescope shown here has had its finder scope removed for extra safety. Projection of the Sun's image in this way allows several persons to view the Sun simultaneously. Artwork by Victor Costanzo.

Your telescope is designed first and foremost to gather light and concentrate it, but in the case of the Sun this results in a dangerous situation. In fact, a piece of paper placed at the eyepiece of a telescope aimed at the Sun can be ignited by the concentrated heat! Obviously, you don't want to place any part of your anatomy, much less your eye, at that point. The object of special solar observing equipment is to reduce the tremendous amount of heat and light reaching your eye while allowing you both magnification and resolution of solar detail.

Basically, there are three different ways to convert your telescope into a solar instrument, but only two of these are really safe. First, a filter can be used in connection with the eyepiece to reduce the emerging light, or second, you can use an aperture filter to reduce the amount of solar radiation entering your telescope in the first place. The third (and most common) method is projection of the image. In addition to these three methods, highly sophisticated (and expensive) equipment is available for those interested in more specialized solar study.

Eyepiece Filters

This method is not recommended because of the danger involved. A very dense filter, usually called a *suncap*, is placed directly over the eyepiece — at precisely the hottest point of the light path. Although these filters are indeed dense enough to reduce the visible radiation to a safe level, they can transmit dangerous amounts of



infrared and ultraviolet light. Futhermore, they can all too easily crack or break under the extreme heat. And if that beam of unshielded solar radiation were to enter your eye, you could be blinded before you could even blink — or at the very least suffer serious and permanent eye damage.

There are eyepiece filters which are designed to be used in connection with Herschel wedges, solar prisms, or an aperture filter, but these are quite distinct from the true suncap. Herschel wedges and solar prisms make use of glass surfaces to reflect most of the solar light out of the optical path. Only about 95% of the total is so eliminated, however, so an eyepiece filter is necessary to further reduce the intensity down to the required 0.001%. Since most of the heat has been eliminated before the light reaches the eyepiece, though, there is considerably less danger involved with these filters. But Herschel wedges and solar prisms, while relatively safe, inexpensive, and easy to obtain, are often difficult to install and use.

Once again let us emphasize that *no* filter, no matter how dense or supposedly "safe," should be used alone at the eyepiece. And *never* use a suncap filter.

Aperture Filters

These filters reduce the solar radiation to a safe level before it even enters your telescope. Aperture filters allow only 0.001% or less of the normal brightness to pass through — a safe level which will produce an image at the eyepiece no brighter than that of the Moon. There are several advantages to this: first, heat is prevented from entering the optical system altogether, avoiding both danger to the optical elements and distortion of the image due to convection currents within the telescope. Second, such a filter allows fully safe direct viewing of the Sun with all of your eyepieces (and therefore magnifications).

There are two types of aperture filters: *full* and *partial*. Although both fit completely over the end of your

Daily drawings of the positions of sunspots, such as the one above made on May 1,1979, are an easy way to follow the progress of solar activity. You will also see the sunspots move across the face of the Sun as it rotates on its axis. A solar projection screen (see diagram opposite) makes such drawings easy to do. Drawing by Philip A. Havey.

telescope, the full aperture filter is the same size as your objective lens while the partial filter is normally much smaller. Partial aperture filters designed for telescopes with secondary optics (in practice, anything other than a refractor) locate the small filter off to one side of the full aperture mask to avoid the obstruction of the secondary.

The disadvantage of partial aperture filters is that you sacrifice a certain amount of resolution and image quality in return for a lower cost. A 2-inch partial aperture filter is cheaper than, say, a full 8-inch filter for an 8-inch telescope, but you have effectively converted your 8-inch into a 2-inch instrument. Formerly, when the difference in cost was much greater than now, partial aperture filters were common, but now excellent full aperture filters are available at reasonable prices.

Image Projection

Eyepiece projection of the solar image is the easiest and most straightforward method of observing the Sun, although the image quality and resolution won't be as good as with a full aperture filter. The greatest advantage of the projection method is that it allows a number of persons to view the Sun simultaneously — especially desirable during a solar eclipse. The only special equipment you need is a suitable screen of some sort, which can range from a sturdy piece of cardboard with a flat white surface to a commercial solar projection screen.

In image projection, the telescope is set up normally (except for the finder — see box), with an eyepiece inserted. The eyepiece used should be a Huygens or a Ramsden — *never, never* use an eyepiece with cemented elements (such as an orthoscopic) for solar image projection, because the enormous heat passing through the eyepiece can easily melt the cement between its lenses and damage the eyepiece. In any case, a low magnification (showing the entire solar disk) is preferable with this method, as higher magnifications tend to be too dim.

The size of your solar image will depend on how far from the eyepiece the screen is placed. You can achieve best results with an image between six and twelve inches in diameter — larger images may become too dim, and smaller ones will make detail too difficult to see. Experimentation will quickly show you the optimum image size for your particular aperture and focal length.

The projection screen may be hand-held, but this is not really desirable because of the unsteadiness involved. Some sort of attachment which will hold the projection screen rigidly to the telescope (so that the image remains in focus at the proper distance) is far better. Many manufacturers offer solar projection screens for their telescopes as accessories, if one is not included with the telescope in the first place, and it is quite easy to build your own as well.

Refractors and telescopes whose eyepieces are in line with the objective may require an additional screen around the drawtube in order to shield the projection screen from the direct light of the Sun. Such a shade is also often a good idea with Newtonians as well, in order to help darken the background. In fact, anything you can do to eliminate stray light from the projection screen will improve the image quality and contrast.

One great advantage of the image projection method is that it makes drawings of sunspots in their correct positions and shapes relatively easy to do. With a pre-prepared circle on a sheet of drawing paper, it's an easy matter to align the solar image with your circle and mark the positions of sunspots and sunspot groups. Unless your telescope is extremely steady — or you forego the convenience of an attached screen — you must be careful of vibrations induced by your artistic efforts. An interesting project is to make drawings on a number of successive days on tracing paper and then superimpose the series of drawings to show the relative motion of the sunspots across the face of the Sun as it rotates.

Advanced Equipment

Those who wish to engage in serious solar observing must be prepared to make a considerable investment and purchase a *hydrogen-alpha filter*. Such a filter (which includes an aperture filter as well as the filtering apparatus itself at the eyepiece) passes only a very narrow band of light centered on the hydrogen-alpha line at 6562.81 Angstroms.

The Sun becomes a spectacular sight when seen at this particular wavelength, because such features as *prominences, filaments, solar flares, plages,* and *granulation* stand out clearly. Prominences are enormous flames of hydrogen exploding out from the Sun's edge, often large enough to engulf our whole planet. (When seen against the background of the photosphere, they are called filaments.) Plages appear as bright irregular patches, usually found near sunspots, while solar flares are shorter-lived bursts of light on the photosphere.

Bandwidths of H-alpha filters vary from 0.65 to 1.2 Angstroms, and the narrower the filter band, the higher will be the contrast (and price). The wider bandwidth is satisfactory for observing prominences on the solar limb, but detailed study of active events on the photosphere requires a narrow bandwidth.

Observing the Sun

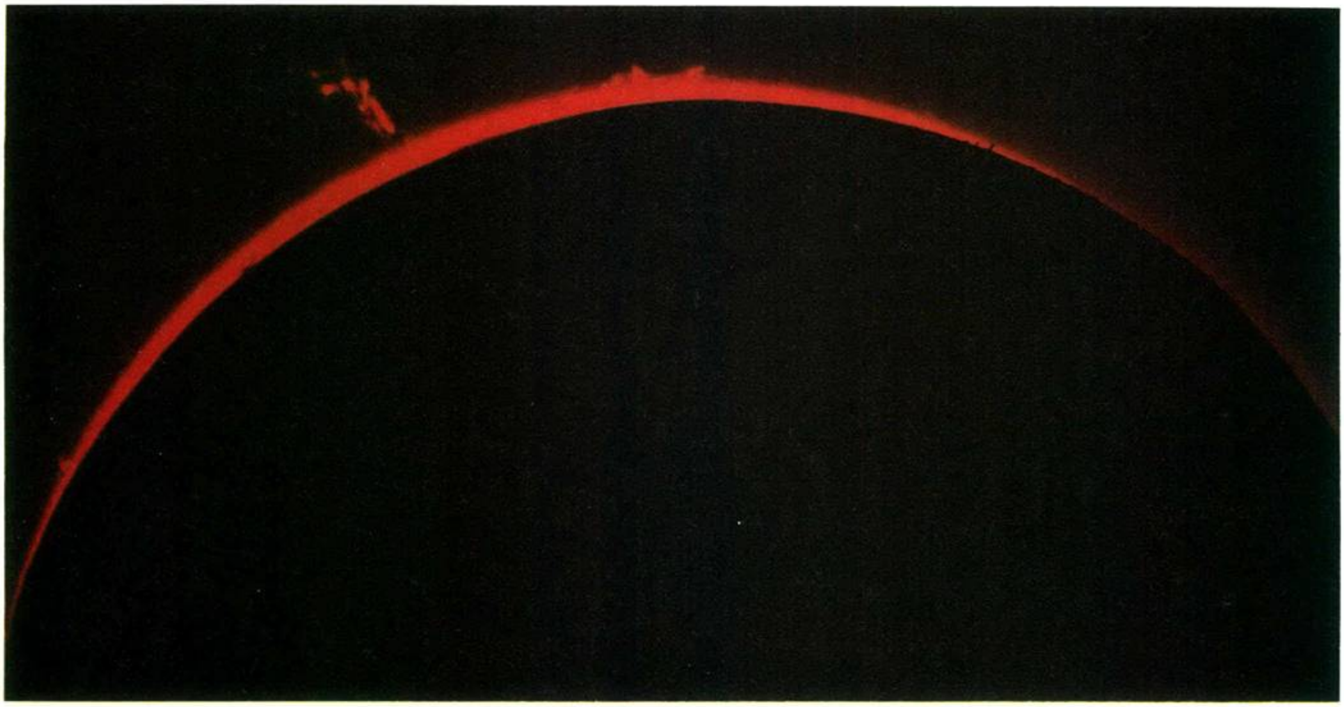
What can you expect to see if you look at the Sun properly?

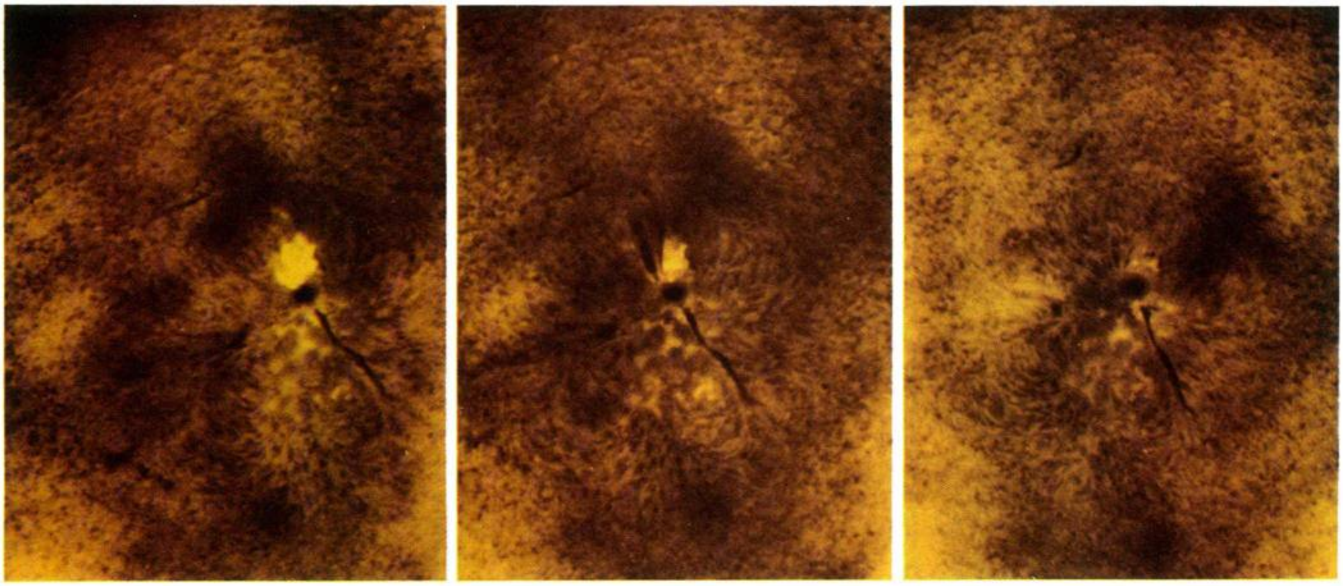
That will depend in the first place on your equipment. Easiest of all, and yet fascinating to observe, are the dramatic *sunspots*, for which little is required. Individual spots appear, develop, drift across the visible disk as the Sun rotates, and vanish in a matter

Look at the Sun...but Watch Out!

It would be wise for sungazers to approach their fiery subject with a measure of caution. In particular, remember the following rules:

- Always cover the objective of your finder and any other secondary scopes before aiming your telescope at the Sun.
- Never look at the Sun directly with your eyes. In particular, don't try to aim your telescope by sighting along the tube. This is unnecessary — just watch the shadow of the telescope tube and adjust it until it is a perfect circle. Your scope will be automatically aimed right at the Sun.
- Never use a suncap or any eyepiece filter without other equipment, such as a Herschel wedge, solar prism, or aperture filter.
- When projecting the image of the Sun, don't use an orthoscopic or any cemented eyepiece. And be careful to keep your hands away from the exit pupil when focusing or changing eyepieces.
- When projecting the image of the Sun, it's a good idea to move the telescope away from the Sun periodically to avoid overheating.
- When using an aperture filter, make sure it is securely fastened to the telescope.
- Never use exposed photographic film as a filter for any purpose, including looking at the Sun with your eyes alone. Although they may look dark, most films allow infrared radiation (the most dangerous kind) to pass right through.





Top: An H-Alpha filter in combination with a solar disk mask makes such dramatic photos of prominences as this possible. Photo by Harry W. Miller. Bottom: The fading of a solar flare is clearly recorded in this series of photos made with an H-Alpha filter used in conjunction with a Celestron 14. Photos by Ed Hirsch.

of weeks. It can be an interesting project to follow the progress of a particular spot or group of spots as it changes from day to day. At solar maximum (now) you may be able to see some groups that even last through several complete rotations of the Sun.

There are several other things which don't require expensive special equipment such as H-alpha filters to observe. One is the phenomenon of *limb darkening.* The bright surface of the Sun becomes noticeably darker toward the edges (or limbs) of the visible disk. This dimming toward the edges, of course, is an apparent effect caused by the fact that our steeper angle of view relative to the visible surface of the Sun (known as the *photosphere*) near its edges doesn't allow us to see as deeply into this hot surface layer as we can in the center of the disk. Also look for plages — faint white mottlings near the limb — which usually accompany sunspot areas.

You will probably also be able to detect a mottled granulation covering the surface, due to the boiling clouds of gas which actually form the photosphere. And if you are lucky, you may see a rare white light flare standing out clearly as an even brighter patch against the brilliant background. These may be more common than usual during the coming months, as the Sun passes through its period of maximum activity.

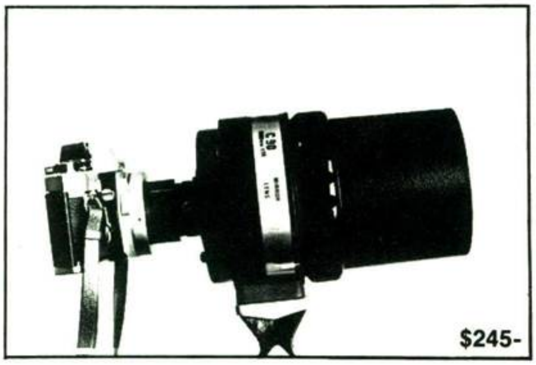
More difficult features to observe — which will require the use of hydrogen-alpha filters as described above — include the solar prominences, plages, normal solar flares, and filaments. With an H-alpha filter, though, you can actually observe changes taking place on the solar surface in a matter of minutes. (See "Photographing the Sun in H-Alpha," ASTRONOMY, January 1978.)

Whatever equipment you use, though, you will certainly find the Sun — the source of all life on Earth as well as much of our energy — an endlessly fascinating object to observe.

-- *Dewey Schwartzenburg*

Celestron 90

Available For Christmas



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ACCESSORIES

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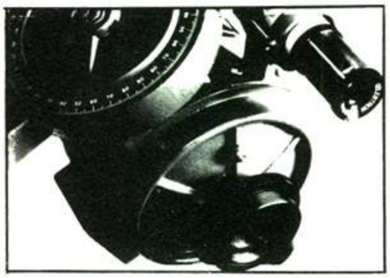

Large Accessory Ring — C90 threaded on the C90 instrument

After Threading the LAR — C90 onto the telescope, the RFA is shown attached.

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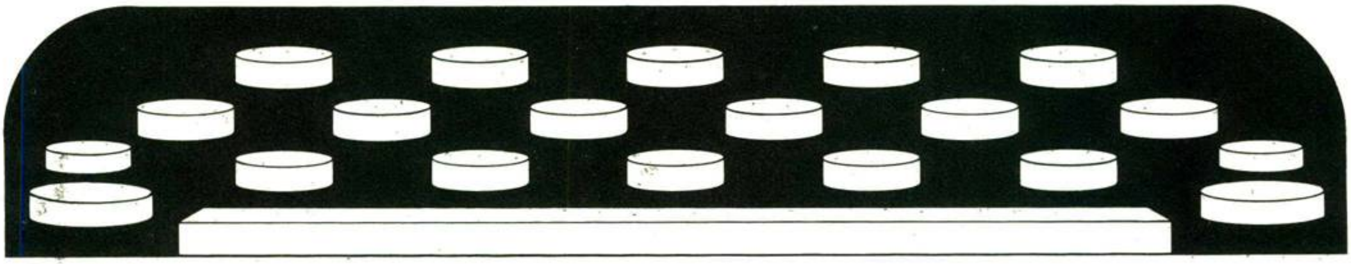

IN FOCUS

Sir / Without wishing to belabor the point, I am nevertheless moved to respond to Mr. Warren Merkey's letter in the September 1979 issue regarding Solar Power Satellites in which he expresses a desire to look "forward to the view to be had from the orbit of the Moon" and doesn't "plan on looking back." This kind of reckless provocation is precisely what we don't need if we are to advance the cause of the conquest and utilization of space. There is already enough of a rift between the "ecology-minded" and the "technology-minded" that we don't need such cavalier attitudes to exacerbate it.

I believe that the SPS will be a disaster for mankind, specifically because (as was acknowledged in the letter) large numbers of such installations will effectively bring Earth-based astronomy to an end. It will happen on *all* scales — from the person who merely enjoys watching the sky from the porch to the professional on Mt. Palomar. But as great as the cost of replacing the professional instruments rendered useless will be, the cost to the human psyche will be far greater. Technological man (and especially urban man) is already frighteningly estranged from nature. City dwellers seldom see plants or animals in the wild state, and see very little of the sky.

Imagine the consequences for humankind when everyone on Earth, however remote from population centers, from the primitive tribes in the jungles of Brazil to the men in Washington who make our laws, can no longer see the stars. Perhaps this will usher in some "new stage" in "human consciousness"; I, for one, shudder at the thought.

The projected drop in the cost of space travel will in no way make up for our loss of the stars: however "cheap" it becomes, most of the world's citizens will be unable to afford it, especially if the world economy continues its downward trend.

The SPS is more Big Technology at a time when small technology seems to be the way of the future. Rather than huge power installations plugged into the existing utility networks, what we need is decentralized, diversified forms of energy delivery, and perhaps an entire rethinking of our energy-use patterns as well. Moreover, what will become of the SPS when fusion power (the truly rational way to generate large amounts of energy) comes online? From the timetables I've seen, the first SPS should be finished just in time to become obsolete.

The conquest of space is necessary enough that its ultimate attainment is pretty certain. We don't need unrealistic schemes (and SPS is unrealistic for more reasons than I've listed) to advance it. If we charge ahead into space with the old ways of thinking and doing, we will only hurt ourselves (as the general public gets turned off by our attitude), and we may find we have merely transplanted our problems to new soil without solving them. As a daydream, the SPS is harmless, but as a realistic projection of another step in the conquest and use of space, the idea of the Solar Power Satellite belongs in the dumper.

Terrence Donnelly
St. Louis, MO

Sir / In regard to Hal Halvorsen's statement, "I'm Not Worried..." (ASTRONOMY, July 1979), you may be interested in reading the booklet "The Satellite Power System Concept" (JSC-14898). It may correct some of the assumptions used by Mr. Halvorsen to conclude that SPS would not be developed.

The current Department of Energy/NASA effort in satellite power systems relies on obtaining comments from concerned and knowledgeable people on all aspects of the concept. Those of us responsible for assessing SPS recognize the large-scale engineering problems associated with this energy system; however, we also see many potential advantages in this concept which, along with the demands for energy and the potential problems of other energy systems, may lead to its development and deployment. Consequently, any attitude which simply dismisses SPS may not be valid and does not serve the interest of an objective assessment.

Francis C. Schwenk, Manager
Space Utilization Systems
Energy Systems Division
NASA, Washington, DC

Sir / Your article "Read 'Um and Don't Weep" (ASTRONOMY, July 1979) was truly the best article I've ever read for beginners buying their first scope. Every word applied to me! I'm in the process of buying a 6″ Dynascope (reflector), so I know all about that so-called "ants in the pants" — I was even considering getting a camera adapter already.

Thank you so much for sending me in the right direction.

Ralph G. Maratta
Hazlet, NJ

Sir / I just can't keep silent any longer. I have never written a letter to a magazine before but I just have to let you know how much I am enjoying your magazine. I just started to read Ken Fulton's article in the July issue, but had to stop to write this letter. How I wish that article "Read 'Um and Don't Weep" had been written 14 years ago when my first move in my newfound hobby (astronomy) was to rush out and buy a 76 mm refractor telescope! Not that I have regrets; to this day I still enjoy my telescope but when I purchased it, I knew nothing about them.

I also might mention the great help ASTRONOMY was in planning "The Great Solar Eclipse Trip of '79" for me, my first experience.

Joanne Larson
Turlock, CA

Sir / On the morning of September 19, 1979 at approximately 5:40 a.m. C.S.T., I observed a brilliant fireball in the northeast sky. I was looking at the Big Dipper when suddenly the fireball came into view slightly above the constellation and rapidly shot downward disappearing just below the handle of the Dipper. It started out white, then turned bright yellow, and then white again before it disappeared.

I have been in the mountains at

night, far from lights, but I have never seen a fireball as bright as this one. Not only did it block out dim stars, but it cast a shadow where I stood.

A slight trail was distinguishable in the sky for about 3 seconds after disappearance. I've done a good bit of observing but this was one of the most beautiful fireballs I've ever seen.

Michael T. Marc
Lombard, IL

Sir / I have been a subscriber to your magazine since its first issue. As a result of your free Astro-Mart section, I have now acquired a very close and dear friend, Mr. Red Wilson of Bakersfield, California.

Approximately six years ago, I put in an ad for information about a certain make of telescope. I had several answers to the ad but only one left itself open for further reply. Mr. Wilson and I began writing letters to each other on the average of one letter a month. We exchanged information about ourselves, and soon we felt as if we had known each other all our lives.

In August of this year I had a chance to meet my penpal. In one of my letters I mentioned that my vacation was coming up soon. His reply was that if I had nothing planned, he and his wife Margie would love to have my wife, my child, and me come visit them. On August 15 at 6:30 a.m. our plane touched down at Bakersfield. Not quite knowing what to expect, we stepped off the plane and without knowing what Mr. Wilson looked like, we looked into the crowd of people waiting for the plane's arrival. Sure enough, I found what looked like a Red Wilson. The next two and a half weeks will be ones I will never forget for the rest of my life. Mr. Wilson and I were invited to tell our story on one of their local television stations. It seems that this station every so often invites the local astronomy club to appear on TV and discuss its activities. From there Mr. Wilson showed us California, Yosemite National Park, Mariposa Grove and its giant sequoia trees, and many other things too numerous to mention.

If it weren't for your free ad, Mr. Wilson and I would not have met. I want to thank you for this service, and I want to thank Red and Margie for putting up with us. May the Lord bless them both.

Ron Bailey
Lantana, FL

Sir / I recently borrowed a nebular filter to test its performance on the gaseous nebulae in the Scorpius-Sagittarius region. Seeing how it decreased the nearby Chicago light pollution, I decided to test the filter's effect on a globular cluster. Since I was in Scorpius, I decided to try the filter on M-4 or M-80. The effects, as compared to those of M-8, M-20, and M-17, were of course small. The real surprise, however, came when I focused on the star Antares. Suddenly, the 6.7 magnitude companion gleamed in a clean split! Although green by comparison, Antares B still appeared green when Antares A was out of the field of view. Without the filter, Antares only appeared to have a faint green sparkle on one side with 100x. Possibly the green color was due to the filter since the color of Antares A was deepened greatly. The separation was noted by several other observers present. Incidentally, Antares B did not move as I rotated the lens nor did it disappear when I used different lenses; the telescope was a 6″.

Barry Rice
Oak Park, IL

Sir / I read the article on nebular filters with some interest and then had a further thought: polaroids!

On the night of August 5th, I constructed a filter for my telescope out of approximately 70% polarized film. I shaped it with a pair of scissors to fit inside my oculars' threads. When I trained my homemade filter on the

Behind the Scenes

More on the 1979 Reader Survey

Last month we concluded with a brief note on the results of our latest reader survey. Here are some more of the fascinating items we learned about ASTRONOMY's readership:

- With a circulation of 100,000 copies of ASTRONOMY, we have far more than 100,000 readers! Why? It seems that the average copy of ASTRONOMY is read by 2.07 readers (no jokes about that poor 0.07 of a person; he's just a statistical slice). So our readership is really well over 200,000.
- 80% of you rate yourselves as medium-level to high-level amateur astronomers. Clearly we're going to have to work very hard to keep you from getting bored — with the best in feature stories and information we can bring you on buying, building, owning, and using a telescope.
- In early 1979, the average reader estimated it took 145 minutes to read ASTRONOMY. Now that ASTRONOMY is bigger and has more departments than ever before (especially the expanded AstroNews and Forum), we're sure that's increased.
- Nearly 60% of our readers read no other astronomical publication. On the editorial staff, we take a number like that very, very seriously. It means that we've got to make sure we bring you *all* the news and *all* the information you need to enjoy your hobby to its fullest.
- Ah yes, ASTRONOMY's readers own telescopes! In fact 60% of you do. Want a breakdown on that? It comes out 46% reflectors, 40% refractors, and 14% catadioptrics. Over 50% of them are in the 4 to 8-inch size range. Furthermore, there are almost 2,000 owners of telescopes with 10 inch and larger apertures out there!
- If we put all those telescopes side by side, their combined optics would have the collecting area of a 1200-inch telescope, equivalent to the light-gathering power of 36 Mount Palomars!
- Those telescopes cost you about $32,000,000 in total, or about $520 each on the average.
- 12,000 ASTRONOMY readers plan to purchase a telescope within the next 12 months, three-fourths of them in the 4 to 8-inch size range.
- Continuing the zany line of thought above, if most of them were 6-inch telescopes, then you're going to buy the equivalent of a 660-incher this year. That's about nine Palomars worth! (I wonder if the Space Telescope program could use your help?)
- Our advertisers will be impressed to learn that's about $9,000,000 — in telescope sales alone — that ASTRONOMY readers plan to spend.
- What do you consider important in buying a telescope? Well, in order of importance, you care about: optical quality, mechanical quality, portability, and price. Very sensible.
- To harken back to monetary matters once again (for just a moment, please bear with me), 47,000 ASTRONOMY readers plan to buy accessories (including eyepieces, filters, star charts, camera mounts, and the like) totaling nearly $9,000,000 — an amount well in excess of many major professional observatories' operating budgets for the coming year.

We're now at the end of the 1970s. The world has changed a lot since the night in 1960 when I first saw Jupiter and Saturn in a homemade telescope and got myself hooked on space. Astronomy is slowly becoming more important in the world. With astronomers out of the dome and on the TV tube spreading awareness, with the general public beginning to tire of mindless fare and seeking more substantial entertainment, and with fuel and energy shortages forcing people to seek less exuberant hobbies, astronomy is very likely to prosper in the 1980s. The night show is there for everyone to see, and the show itself is free even if the telescopes, binoculars, and eyepieces cost a bit. And we're all invited.

Richard Berry

Richard Berry
Editor

stars, I was quite surprised when I could see Vega's purplish hue and the blood-red of Arcturus. (Both are usually a glaring white due to Washington's hazy summer skies.) The colors were surprisingly bright.

The filter is easy to make and inexpensive (I found my polarized film in my scrapbox), and achieves excellent results. I actually saw more stars with the filter in some parts of the sky than without it! It's well worth the little time and effort put into its construction.

Wayne Wagner
Bethesda, MD

Sir / On the morning of Sept. 6, I woke up early to view the eclipse. The weather was very clear after Hurricane David came through and dumped over 4 inches of rain the day before.

I noted a star near the Moon at 4:30 a.m. E.D.T. and at 4:41 a.m., I first saw the penumbra move onto the Moon. I watched the star as it got closer to the Moon. Just as it occulted the star, the Moon entered the umbra at 5:18 a.m.

At 5:22 a.m. I saw the star moving away from the Moon. (The star was Lambda Aquarii.) At 5:30 a.m. I noted another star close to the Moon. Then at 6:15 a.m. I saw that twilight was coming up.

The Danjon scale of the eclipse was hard for me to assess due to the bright sky at total eclipse, but I'd guess L-2.

The Moon was invisible just before it set at 6:40 a.m.

Donald H. Talbert
Greensboro, NC

Sir / In the Star Dome for June 1979, you asked for comments on the powers needed to split Zeta Bootis. Using a Quantum Four and a 10 mm Clave eyepiece with a 1.75x Barlow giving a power of 266, I split Zeta high, wide and handsome. Two distinctly separate disks in contact were seen. In color they appeared to me to be of a light lemon hue. My enthusiasm stems from the fact that in this forsaken area we get nights like this only about a dozen times a year.

Theodore Pollock, M.D.
Passaic, NJ

Sir / I was surprised to see Jay M. Baker's photograph of Lyra in the October 1979 issue. This photo was taken in Crook County, Wyoming (N.E.) probably from the traffic circle area on the west side of Devil's Tower.

As a boy I used to ride this country horseback and often slept near there with a saddle for a pillow and a horse blanket for cover. I'd watch the stars for hours thus and would've been thrilled to have had even one issue of ASTRONOMY. These outdoor experiences are probably why I subscribe now.

Harold E. Dillon
Independence, MO

Ooops!

Through an editorial oversight, Michael Witkoski's name was misspelled in the July Gazer's Gazette. Our apologies for any embarrassment caused.

The graphs accompanying the August Gazer's Gazette on meteor photography don't match the description in the text because they were redrafted for publication. They are completely accurate, however. Use the labels in the graphs and common sense as a guide, and you won't go wrong.

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Observe a Quasar!

by James Mullaney

For the experienced observer looking for new challenges, the enigmatic quasars (or quasi-stellar objects) are easily among the most intriguing celestial objects in the sky. These strange denizens of deepest space are thought to be the most distant and luminous objects in the observable universe — incredibly remote and powerful cosmic beacons hidden at the outer edge of space and time.

Due to their bizarre nature and vast distances from us, the visual sighting of the brighter quasars in amateur-sized telescopes can be a thrilling experience for modern-day stargazers. Most observers, thinking of quasars as the special province of only the world's greatest optical and radio observatories, are surprised to learn that some of these objects actually lie within reach of their humble backyard instruments. Their surprise is certainly understandable when we realize that even the nearest of them are more than a billion light-years from us.

Quasars were first recognized in 1963, when the mysterious unidentified lines in their spectra were decoded in a brilliant flash of insight by astronomer Maarten Schmidt at the Hale Observatories. Plates taken with the 200-inch reflector on Mt. Palomar of their brightest representative — 3C 273 in the constellation Virgo — showed its spectrum to be enormously redshifted, its recessional velocity implying a distance on the order of a billion light-years. Later work confirmed this spectacular conclusion and increased this figure to some three billion light-years (corresponding to a recessional speed of 30,000 miles per second). Today, literally thousands of quasars are known — nearly all having even greater redshifts than 3C 273.

To be visible at their vast distances, quasars must be actually hundreds of times more luminous than a typical giant galaxy. Yet — as their name "quasi-stellar" implies — they appear starlike in even the world's largest optical telescopes. Even more strange, they vary in their light output, often changing in brightness by several magnitudes over a period of a year or more. In addition, they exhibit fluctuations on the order of a magnitude or less in a period of days or weeks and rapid erratic flickerings of a fraction of a magnitude over hours or even minutes.

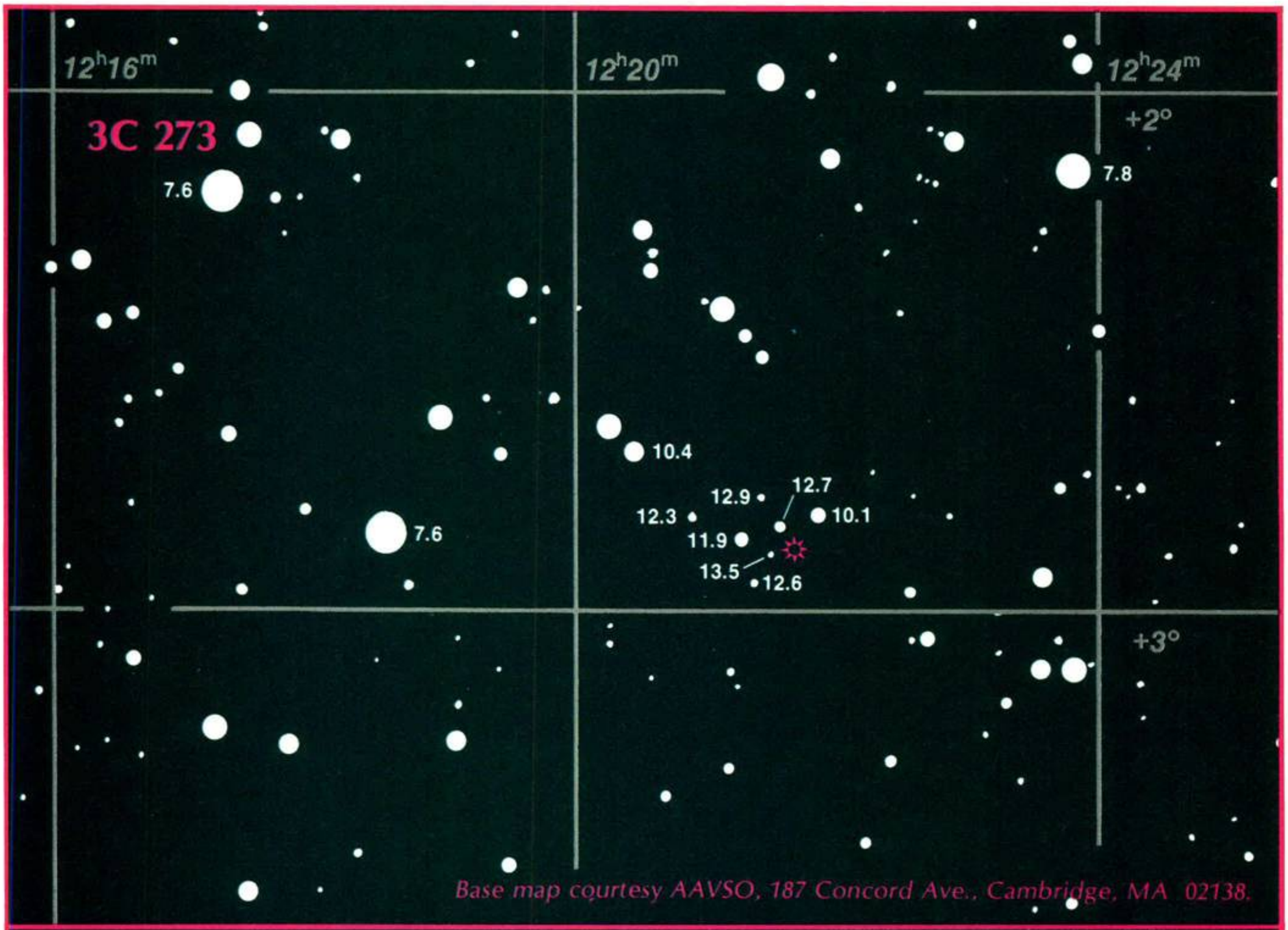
The great mystery about quasars is that they appear to be far too small to generate the amounts of light and other radiation they do, much less maintain that output over such long periods of time. No known source of energy — even matter-antimatter annihilation itself — can adequately account for their prodigious expenditure of energy. As one astrophysicist put it: "Quasars are either the most distant observable objects in the universe, or else heralds of new laws of physics waiting to be understood." (For more on the nature and cosmological significance of quasars, see "The Quasar Connection," beginning on page 6 of this issue.)

Whatever their true nature, quasars are fascinating objects to search out and identify in medium to large (6 to 16-inch) aperture instruments. The accompanying table lists a few of the best-known brighter specimens as beginning targets.

Some comments on this sampling are in order. First, the entries appear in order of approximate visual magnitude. However, all quasars are variable in brightness, some more so than others. 3C 273 ranges from about 12.2 to 13.0, its average being near 12.5 magnitude — giving it unquestioned first place in any such listing. 3C 249, on the other hand, becomes as bright as 14th magnitude at maximum but drops nearly three full magnitudes to 17th at minimum light. This means the relative order of brightness can change for the fainter objects in the table. It also means that an object plainly visible in a given telescope at one time may be difficult or even invisible at another. Thus, the aperture required to see a certain quasar will depend upon its magnitude at the time of observation, as well as sky conditions and the training of the observer's eye. Therefore it is impossible to specify a "minimum" aperture required to sight a specific quasar.

Another point concerns the two sets of coordinates given, for both epoch 1950 and 1980. Depending on its actual place in the sky, precessional effects by 1980 can be considerable — in some cases placing an object at the edge of even a wide-field eyepiece. While not a serious concern in the case of typical deep-sky targets, hunting the starlike quasars requires the utmost in positional accuracy if they are sought by setting circles alone. The epoch 1950 positions will be helpful in plotting the locations on standard star charts, but the 1980 positions will save considerable frustration at the telescope. Tables like those found in the annual *Observer's Handbook* of the Royal Astronomical Society of Canada and the one published in ASTRONOMY ("Right Ascension and Declination," May 1978) will provide exact precessed positions for other years.

For its limited number of objects, the selection in the table is fairly well distributed around the sky. The second brightest quasar — 3C 249 in Draco — lies only 12½° from the north celestial pole. Being circumpolar, it is conveniently available for viewing at any time of the year. In searching for it as well as the others, a dark (moonless) transparent night is a must. Use a low-power, wide-field eyepiece for


12h16m
12h20m
12h24m
3C 273
+2°
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7.6
7.8
10.4
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10.1
11.9
7.6
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12.6

Base map courtesy AAVSO, 187 Concord Ave., Cambridge, MA 02138.

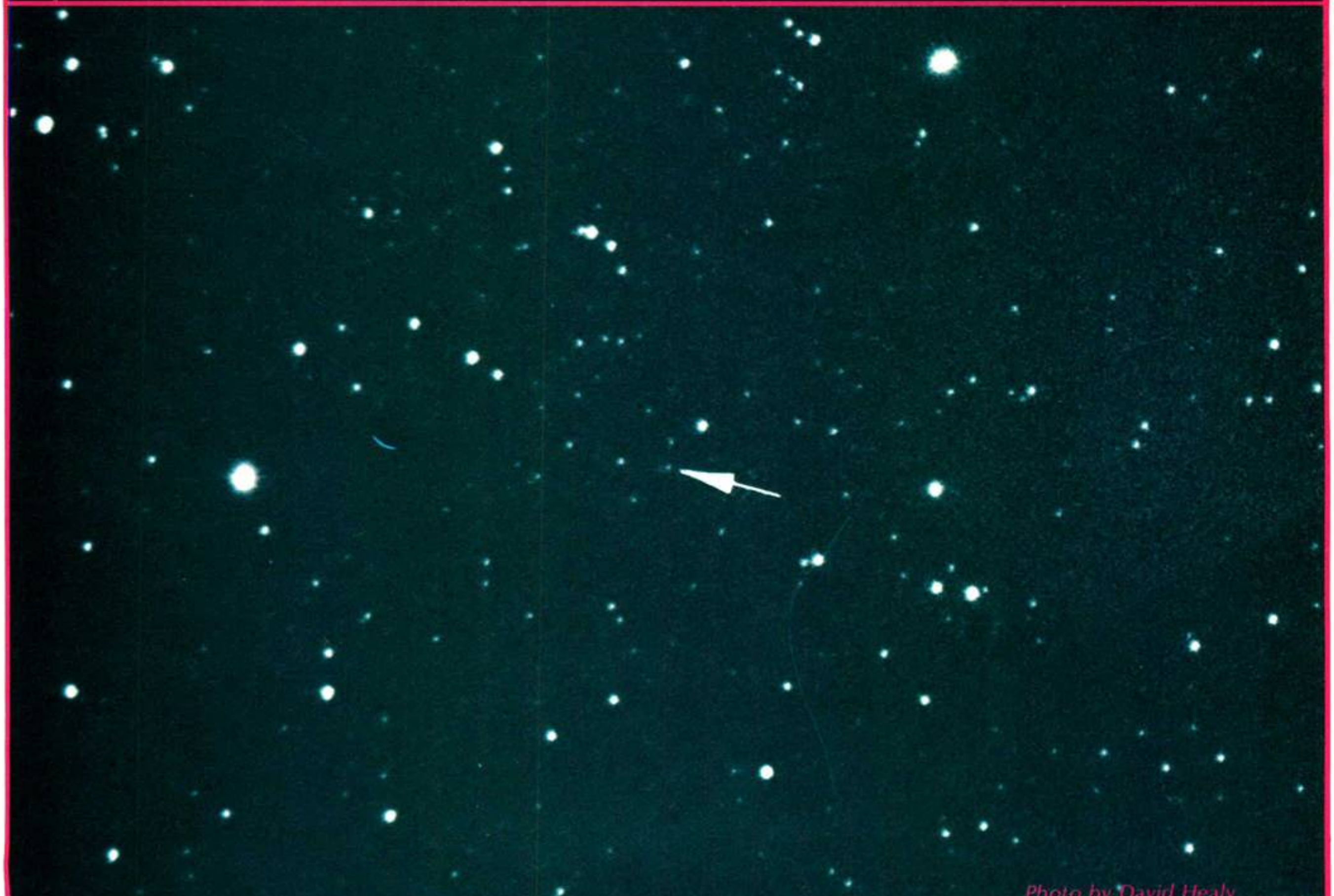


Photo by David Healy

sweeping with the telescope to locate and center the field of the quasar. Then change to a medium power to darken the sky background and zero in on the point of light you think is the object itself. You'll be looking for a very faint bluish glimmer, submerged in the foreground sea of stars.

Most of these targets will require an extremely detailed chart of the immediate field for certain identification. While such aids are available, they mostly appear in relatively inaccessible professional literature. One exception is that of 3C 273 itself, for which a number of maps and field photographs have been widely published. For example, the American Association of Variable Star Observers (AAVSO) provides excellent working charts (on which the chart accompanying this article is based). The AAVSO placed 3C 273 on its program some years ago because of its variations in brightness. Monitoring the magnitude of this quasar is an interesting and valuable undertaking for those observers well-acquainted with this object. Both our chart and the AAVSO's provide accurate visual magnitudes of surrounding field stars, making them ideal for this purpose. Such work provides a heady adventure for the stargazer — actually observing from your own backyard the variability of mysterious objects half-hidden in the night billions of light-years from Earth.

With such a roadmap in hand, let's examine in more detail the brightest and most easily observed of all the quasars. 3C 273 lies in Virgo near the celestial equator, 3½° northeast of the 4th magnitude star Eta (15) Virginis and about a degree south and 2° east of 5th magnitude 16 Virginis. Another marker is the 11th magnitude spiral galaxy NGC-4536 — the quasar lies just 1½° due west of this 7 by 2 arc-minute object.

3C 273 can be glimpsed by a experienced observer in a 5-inch refractor at as low as 25 power on a dark night and can be seen without difficulty in a 6-inch reflector at 30 to 50 magnification. Its presence is quite definite in 8-inch telescopes at 60 to 100 power, while larger instruments enhance its eerie blue color. At peak brightness and under ideal sky conditions, this object should even be within reach of a 4-inch with averted vision — something you might like to test for yourself.

3C 273 is the brightest and easiest of all quasars to observe. Its magnitude, however, can vary greatly, so no hard-and-fast rules can be laid down about the minimum aperture necessary to see it at a particular time. The finding chart and photograph opposite will help in identification, and the magnitudes of comparison stars will aid in making an accurate estimate of its current brightness.

THE BRIGHTEST QUASARS

Object	Constellation	R.A. (1950)	Dec.	R.A. (1980)	Dec.	Mag. (max)
3C 273	Virgo	$12^h27^m32^s$	+02°20.5′	$12^h28^m04^s$	+02°10.5′	12
3C 249	Draco	$11^h00^m12^s$	+77°30.0′	$11^h02^m30^s$	+77°20.3′	14
3C 345	Hercules	$16^h41^m19^s$	+39°51.0′	$16^h42^m19^s$	+39°47.7′	15
3C 147	Auriga	$05^h38^m44^s$	+49°49.4′	$05^h41^m04^s$	+49°50.3′	15
3C 48	Triangulum	$01^h34^m49^s$	+32°52.8′	$01^h36^m32^s$	+33°01.9′	16

Like most quasars, 3C 273 displays complex variations in its light output. There appears to be a primary fluctuation of about a magnitude in a very rough period of 13 years. Superimposed on this are other, shorter-term changes in brightness, among which are brief "flashes" amounting to nearly a full magnitude and extending over an interval of several days to a week or more. But beware of a spurious "blinking" in and out of view, due to turbulent air on a night of poor seeing, especially if this object happens to lie at your particular magnitude limit.

The starlike image of this quasar measures less than one arc-second in apparent angular size and is officially known as 3C 273A by astronomers. An extremely faint but powerful optical "jet" (designated 3C 273B) is also present, extending 20 seconds southwest of the main object itself. This strange feature measures over 300,000 light-years in length and is the source of most of this quasar's intense radio emission. Unfortunately, you couldn't see it even in the largest optical telescopes — only time-exposure photos reveal its presence.

3C 273 provides a good "warm-up" before attempting to see the other, dimmer quasars given in the table. You need not wait until spring to try it either, since Virgo is visible in the predawn sky during the winter months. The second object on the list — circumpolar 3C 249 — requires a 10-inch telescope to be seen with certainty even when it's near its maximum brightness, while the remaining ones will tax the capabilities of 12 to 16-inch instruments.

When their baffling nature and possible grand significance in the cosmic scheme of things is appreciated, catching sight of a quasar can be a thrilling experience. It is nothing less than amazing that a small disk of glass can capture and bring into focus the ancient photons of light which have traversed the expanse of the observable universe on a journey lasting billions of years. Truly, the telescope is a magic time machine which makes possible vast journeys across the cosmos in sight and mind at the turn of a knob!

AstroNews

Space Station Salyut 6 Completes Mission

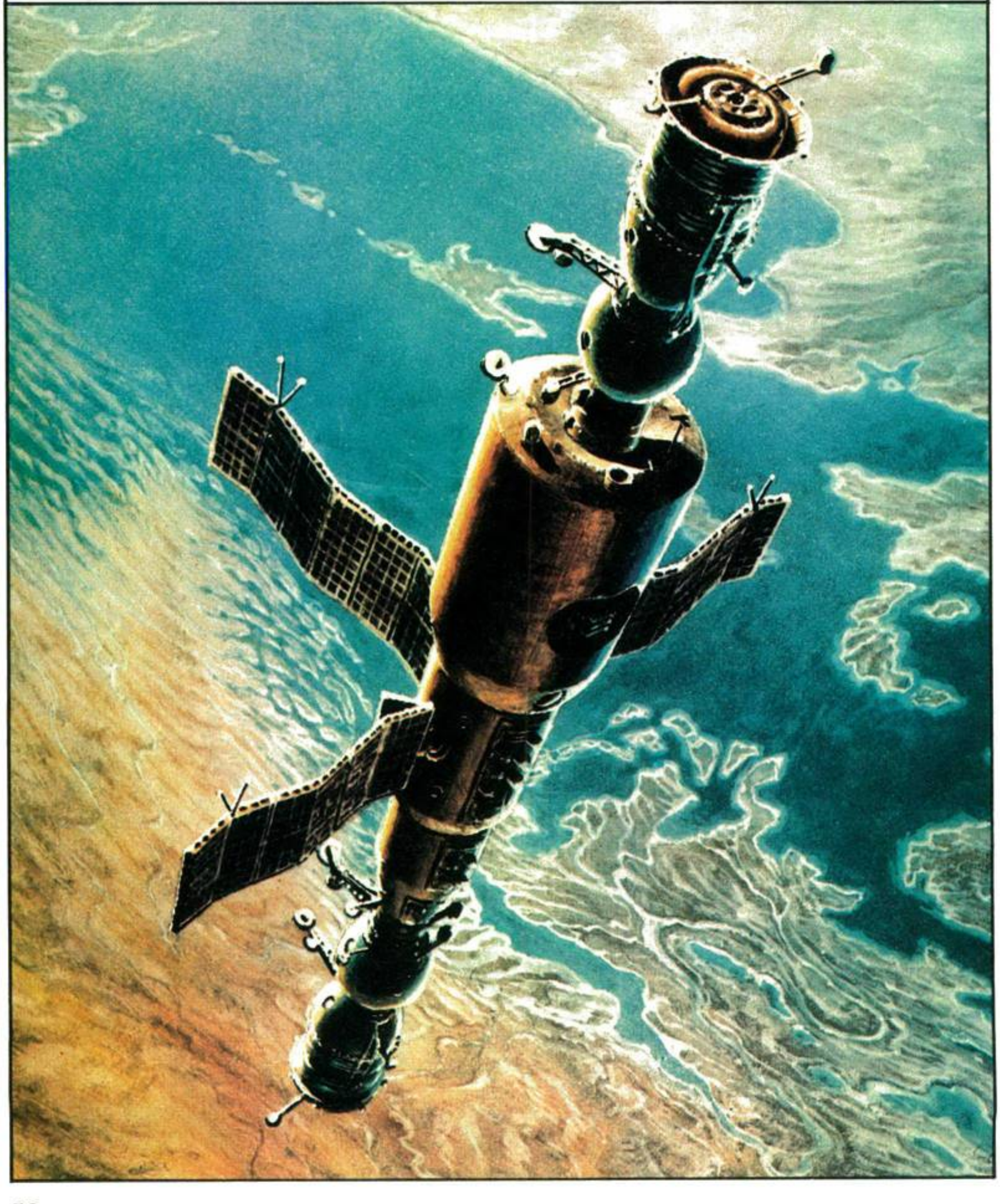
Soviet manned space activity in the past year has gone a long way towards laying the groundwork for the realization of the official Soviet space goal: the establishment of permanent orbiting space stations with interchangeable crews. This target has been explicitly forecast for several years; the recent space missions connected with Salyut-6 underscore the reality of Soviet intentions and their capabilities to carry them out.

Since Salyut-6 was launched in late 1977, crews of cosmonauts have carried out an impressive program of scientific research, as well as an ever-expanding program of research with immediate practical benefits such as earth surface photography and materials processing. They have repeatedly broken endurance records by marathon flights lasting 96 days, then 140 days, and most recently 175 days. Perhaps most significant, the Soviet space program management has shown hitherto uncharacteristic confidence and flexibility when dealing with technical setbacks, and has boldly rescheduled subsequent space missions to compensate for embarrassing failures.

The Salyut space station is a 42,000 pound cylinder comprised of a central working module and two airlock/transfer modules at either end, each containing a docking port for visiting spaceships of the Soyuz and Progress models. Power is provided by three solar panels which sprout from the central cylinder. The forward airlock module also has a side hatch for direct access to space during extravehicular activity (EVA). The aft airlock is surrounded by the tanks and plumbing of the Salyut's onboard maneuvering engine which is used periodically to raise the orbit of the station against the effects of air drag (and which will also be used to bring the station down over open ocean at the end of its mission).

The Soyuz spacecraft are seven-ton vehicles which carry a crew of two cosmonauts into orbit and back to Earth. Flights of these vehicles are limited to about 90 days. The Progress spacecraft (a modified Soyuz design) are robot-controlled unmanned freighter-tanker vehicles which transport supplies, air, water, and rocket propellants to the space station; their flight times do not exceed thirty days. By a judicious combination of dockings at both ports, and a careful schedule of resupply and relief flights, a crew of cosmonauts can be supported in space indefinitely. Salyut-6, the first space station to utilize two docking ports, thus can be considered to be a prototype of a permanently occupied space outpost.

The Soviet space station Salyut 6 is seen below in orbit over the Aral Sea. In this representation, both the forward and aft docking ports are being used. Four separate expeditions have manned Salyut 6 during the past two years. Artwork by Andrei Sokolov.



The fourth (and last) expedition occurred in 1979, and was considered a "bonus" flight since the original purposes of the Salyut-6 mission had all been accomplished by the second and third expeditions. When the new cosmonauts were launched in late February 1979 (Soyuz-32), they were to attempt to repair and replace worn-out equipment on the Salyut, verify the results of earlier medical experiments, conduct additional scientific and engineering experiments, and host three additional visits of "guest cosmonauts" from Bulgaria, Hungary, and Cuba. All of these goals but the last were met.

After receiving one supply ship at the aft docking port, the Salyut was ready to host a visiting Soyuz which would result in the exchange of the crew's "old" Soyuz for a fresh one. However, the rendezvous of the visiting Soyuz (#33) failed and it had to make an emergency landing. The cosmonauts in orbit were in no danger but there was concern over their aging Soyuz, so when it came time to launch another visiting flight (after a second supply ship had also docked for several weeks at the aft port) the new Soyuz was launched unmanned; this spared a visiting team of cosmonauts from having to risk their lives returning to Earth in an old Soyuz of questionable reliability. The new Soyuz (#34) docked at the aft end successfully; the cosmonauts on Salyut loaded their old Soyuz with samples and results of scientific experiments and sent it back to Earth on autopilot. They then got into the new Soyuz at the aft end and flew it around to redock at the front end of their space station, after which the now-clear aft end hosted yet another unmanned supply ship (Progress-7). Plans for additional visits by guest cosmonauts were cancelled and the cosmonauts returned to Earth in August after nearly six months in orbit.

However confusing these complex maneuvers may seem, they allow Soviet space planners a wide range of alternatives for the operation of space stations, particularly in light of occasional failures. Such flexibility, and the confidence to execute such plans, mark a major new plateau in Soviet space operational capability.

Activities on the Salyut-6 were of several types and can be classified as follows: medical, biological and life support; Earth resources and mapping; technological development; materials processing; astronomical; and political. One of the most valuable aspects of the Salyut-6 mission was the ability to recycle experimental results into the implementation and execution of new experiments. Frequently, cosmonaut crews would conduct work, send the raw material back to Earth, and then have sample results sent back up to them as guidance to improve their subsequent work.

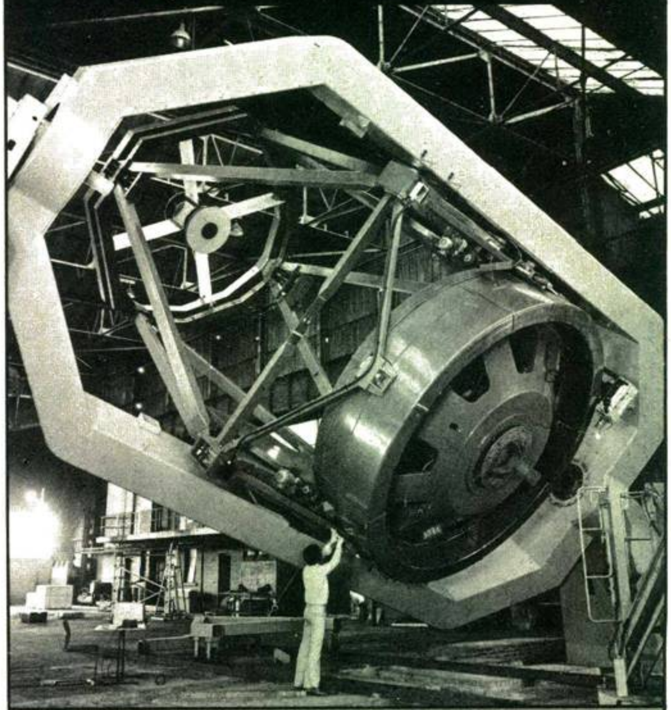
The medical activities were primarily intended to maintain the cosmonauts in good health, both during the flight and during the stresses of the eventual return to Earth. Physical exercise lasted two hours a day per man, and constant stresses were placed on the cosmonauts' muscles by the wearing of special elastic suits which required them to flex muscles unused in space but needed on Earth. The human heart system was stressed by use of a semi-vacuum device, worn as bulky trousers, which used suction to force blood into the lower half of the body in mimicry of gravity, thus keeping the heart muscles from relaxing too much. Soviet space doctors were so pleased with the results of this health regimen that they speak confidently of ordinary duty tours in orbit of twelve months duration.

The biological and life support activities dealt with both physical and psychological support of the space crews. Different types of plants and tissue cultures were exposed to space conditions for varying periods of time, and a number of plants were grown in a small centrifuge called the "biostat." Experimental food crops, including onions, cabbage, and wheat, were tested with the ultimate aim of supplementing, and eventually supplanting, the use of supplies brought up from Earth. Water was recycled from cabin moisture, recovering fifty percent of the moisture used by each crewman. Great attention was also given to ways of maintaining and monitoring the spirits of the crews who spent month after month in space together.

The Earth resources and mapping activities used several different types of cameras. In early expeditions on Salyut-6, almost 80% of the photographs produced were on order for user agencies in the Soviet government rather than scientific research. The system thus can be considered operational. Other mapping programs were devoted to exploring the region near the Baikal-Amur Magistral (the "BAM"), a new railway across Siberia which is opening up vast new regions to economic development. Experiments were also conducted on observation of glaciers, of ocean currents, and of pollution near industrial regions and near river deltas.

The technological development activities tested new equipment for use in future space systems, and checked out operational devices which had been first tested on earlier Salyut missions. Sophisticated new spacesuits, for example, were used for the first time on Salyut-6. A navigation and control system called the "Delta" minicomputer was used to relieve the cosmonauts of much naviga-

UKIRT Dedicated in Hawaii



The United Kingdom Infrared Telescope (UKIRT) is shown shown above undergoing tests in the factory of Donford Hadfields Limited in Sheffield (England) in October 1977. A concrete "dummy" mirror was used in place of the 3.8 meter (150-inch) objective. UKIRT, the largest infrared telescope in the world, is one of four large telescopes on the summit of Mauna Kea in Hawaii. Dedicated on October 10, UKIRT will be used to observe a wide variety of celestial objects in the infrared portion of the spectrum as well as at visible wavelengths. Photograph copyright © 1978 Royal Observatory, Edinburgh.

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tional drudgery. For the first time on a space mission, an onboard television screen was used both for display of videotapes and for live "uplink" of ground images. On a platform near the airlock hatch, samples of materials were exposed to space conditions for up to a year before being retrieved and returned to Earth.

The materials processing experiments involved the use of two electrical furnaces on the Salyut. By the time the fourth expedition began in 1979, most of the work on these furnaces was not destined for laboratories but was instead executed on orders from instrument building organizations and other end users. In other words, the Salyut became an operational space workshop. Experimental work was also done on the highly sophisticated process of vapor deposition, in which metal ions are "sprayed" in a vacuum onto a surface to be coated.

The astronomical experiments involved the use of an onboard telescope, which used a liquid-helium-cooled sensor system to observe stellar targets in the near infrared. In addition to stellar and planetary observations (which were conducted only infrequently due to the excessive power drain of the refrigeration system needed to maintain liquid helium), the telescope was used to observe the extinction (the "setting") of stars in the Earth's atmosphere and thus measure the various levels of pollution in the air by the frequencies at which they blocked starlight. A gamma ray telescope was installed on Salyut by the fourth expedition, but the most impressive device by far was the KRT-10 ("cosmic radio telescope, 10 meter") antenna which was tested in July-August 1979 by the last expedition. This, the first radio telescope to be erected in space, was employed together with a 70-meter dish in the Crimea as a test of the techniques of long baseline interferometry for the observation of radio targets in the Milky Way.

The political activities involved the visits to the Salyut of "guest cosmonauts" from Soviet-bloc nations.

A particularly significant accomplishment of the fourth expedition, which was in other ways not greatly distinguishable from earlier visits, was the repair of the Salyut by means of modular replacement of worn-out equipment. The space station was built to be repairable, thus allowing its lifetime to be extended considerably over that of earlier types of space stations. All future space stations will be based on this design philosophy, and the success of the fourth expedition in giving the station "a second wind" is the most important step towards permanent space stations since the first Salyut and Skylab flights in the early 1970s.

For the future, Soviet spokesmen predict that permanent space stations will be assembled from modules launched separately and connected in space by "kosmobuksir" (space crane) vehicles. These modules could be the size of Salyuts or they could be built from modified Soyuz craft. Mysterious unmanned test flights of man-related space hardware, carried out in the 1977-1979 period but not well understood by Western observers, could be connected with the development of such modules.

Another future need is a more efficient passenger vehicle for the transport of cosmonauts to and from the larger space station. Soyuz has been in operation since 1966 and will probably be replaced soon. There is much speculation concerning the development of a winged reusable "Soviet space shuttle" capable of carrying up to six cosmonauts.

If the purposes of many recent Soviet space flights seem unclear, their very volume speaks plainly of the fact that Moscow is quite serious about fulfilling its promise of establishing permanently occupied space stations in Earth orbit in the immediate future. The time may shortly arrive when space will become occupied continuously by human beings, with tired cosmonauts being replaced by fresh crewmen ferried up by reusable shuttles to permanent space stations. The Salyut-6 expeditions demonstrate both the seriousness of Moscow's intentions, and the breadth of capabilities available to the Soviet space program.

New Jovian Moon Discovered

This computer-enhanced photograph, taken by Voyager 2 on July 8, shows a new jovian satellite at left (the other white streak is a star trail). The moon orbits at the edge of Jupiter's ring, visible here as a gray diagonal blur. NASA photograph.

A new moon of Jupiter has been discovered in pictures taken July 8 by NASA's Voyager 2 spacecraft during its excursion through the jovian system. While studying pictures of Jupiter's thin ring of particles taken by Voyager 2 cameras less than 24 hours prior to the spacecraft's close passage by the planet, two researchers at the California Institute of Technology — graduate student David Jewitt and scientist G. Edward Danielson, a member of the Voyager Imaging Science team — determined that a starlike object in the ring plane was a moon.

Temporarily designated 1979J1, the new satellite is the 14th known to be circling the giant planet. (Another possible moon, farther out from Jupiter and awaiting confirmation, may have been seen in Earth-based photographs several years ago by Charles T. Kowal of Caltech, discoverer of Jupiter's 13th satellite.)

1979J1 is the closest moon to Jupiter, orbiting the planet at the outer edge of the ring about 57,800 kilometers (36,000 miles) from the cloud tops. It is estimated to be only 30 to 40 kilometers (18 to 25 miles) in diameter, smaller than seven of Jupiter's other moons but larger than six.

The new satellite's orbital period is 7 hours, 8 minutes, which makes it the fastest moving satellite in the solar system.

The first hint that the apparent star-trace photographed by Voyager 2 was a jovian satellite came when Jewitt and Danielson, after an exhaustive search, found no star in the vicinity. This led to examination of another Voyager 2 photo of higher resolution showing the same portion of the ring, the same curious object, and some trails of known stars. An orbit was then calculated.

Voyager scientists believe 1979J1, because of its location at the outer edge of Jupiter's ring, may directly influence the composition of the ring either by sweeping out or supplying ring particles.

Adaptable Life

Although no evidence for extraterrestrial life has yet been found, most scientists have little doubt that life forms have indeed evolved elsewhere in the universe. The big question, though, is how common is life? One reason why this question has been so difficult to answer is because scientists don't yet understand the complete process by which organic matter arises from the inorganic.

A University of Texas chemist has recently made an important contribution to this understanding by demonstrating that amino acids, the fundamental building blocks of proteins necessary for all animal life, can be produced by sunlight alone. There are only 20 common amino acids which make up all the proteins found in living organisms on Earth. While amino acids have been produced before in the laboratory from components present in Earth's primitive atmosphere, previous experiments have used electric discharges. This is the first time these fundamental building blocks of life have been produced by the use of sunlight alone.

Dr. Allen J. Bard, professor of chemistry, reported he produced the amino acids using solar energy to illuminate solutions in which titanium dioxide powders coated with small amounts of platinum were suspended. Titanium dioxide is a common inorganic solid used in some products, such as paints. The basic ingredients Dr. Bard used to make the amino acids — ammonia, water, and methane — are thought to be components of Earth's primordial atmosphere. The platinum-doped titanium dioxide served only to capture the light and use its energy to convert these ingredients into amino acids.

"The powders themselves remain unchanged chemically during the process," Bard said. "They only catch the light and transfer the chemical energy to species in solution. These powders are thus analogous to the chlorophyl-based photosynthetic systems in green plants which utilize sunlight to convert water and carbon dioxide to sugars and oxygen."

Similar reactions in rocks or clays may have played a role in the initial production of amino acids in nature and provided for their continuous production as nutrients for early life until biological photosynthetic systems developed. Thus the origin of life is not necessarily dependent on a plentiful supply of electric discharges in the form of lightning.

In another recent finding, Dr. Cyril Ponnamperuma, a geochemist and director of the University of Maryland's Laboratory of Chemical Evolution, reported he has found amino acids in two meteorites found in Antarctica. Some of the amino acids are different from any found in living organisms on Earth, but Dr. Ponnamperuma pointed out that the amino acids are "clearly extraterrestrial and pre-biotic — not biological." In other words, the organic molecules in the meteorites were formed by physical processes like those discovered by Dr. Bard and are forerunners of life rather than the fossils of living objects.

The meteorites studied are carbonaceous chondrites, a very rare type containing carbon molecules. They were found in Antarctica and are especially valuable because the deep-freeze conditions on that continent retained the meteorites in a pristine condition, with almost no contamination by organic materials since their arrival from space.

"We have found two more examples of prebiological processes taking place elsewhere in the solar system," Dr. Ponnamperuma said in reference to the meteorite study. "The finding gives credence to the idea that the chemical evolutionary process postulated for Earth has taken place elsewhere."

Each of the 20 amino acids can be structured in one of two ways: either "left-handed" or "right-handed." The "handedness" has to do with the direction in which a beam of polarized light turns when it is passed through water in which the amino acid has been dissolved. The "left" and "right" forms are chemically identical mirror images of each other.

"In all the 20 amino acids we know of on Earth," Ponnamperuma explained, "the polarized light turns to the left. The technique used in our laboratory had demonstrated that in the meteorites there are equal amounts of left and right-handed amino acids. In all the prebiotic experiments conducted in our laboratory, we got both left-handed and right-handed amino acids. This is proof that the acids are not the result of a living process, but a pre-life form."

Dr. Ponnamperuma also reported that rocks found in a rugged mountainous area of southwest Greenland contain evidence that life on Earth was present as early as 3.83 billion years ago — more than 400 million years earlier than formerly believed. He said this means the beginning of life on Earth goes back to the early stages of the Earth's history.

"The finding indicates that the time required for life to begin on Earth was much shorter than previously believed," Ponnamperuma said. It has been estimated that the Earth's crust formed about 4.6 billion years ago. This leaves some 800 million years for the oceans to have formed and for conditions to develop that allowed these organic molecules to evolve and flourish.

In still another related finding, two scientists have discovered that life, once it does appear, is even more adaptable to adverse conditions than had been thought. Divers penetrated the 18-foot thick perpetual ice covers of two Antarctic lakes to find enormous mats of pinkish-orange algae growing about 20 feet below the ice. The amount of light filtering down through the ice to such a depth is less than one-thousandth that on the surface, and therefore the algae has adapted to far less sunlight than any other known plants. Furthermore, the algae manage to survive four months of twilight and four more of total darkness, and yet obviously thrive in their icy, near freezing waters.

The scientists who made the discovery are Dr. Bruce C. Parker and Dr. George M. Simmons, Jr., both of the Virginia Polytechnic Institute and State University. According to Dr. Parker, "It may be that algae mats represent life that has maximally adapted to extremely low light and temperatures at the same time."

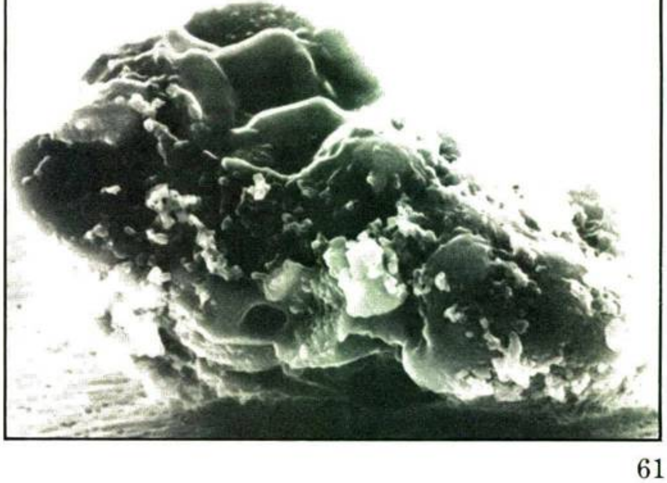
Such extreme conditions exist on many solar system bodies, none of which, other than the Moon and Mars, have yet been examined for the presence of life.

Comet Dust on Earth

Tiny particles of dust that may have been shed from a passing comet have been analyzed successfully by a group of university scientists working for NASA. Their results, reported in an issue of *Science*, suggest that this unique, little-understood extraterrestrial material may contain chemical information dating back to the formation of the solar system 4.5 billion years ago.

The successful analysis of single dust particles weighing only a billionth of a gram (about one 30-billionth of an ounce) was carried out by Dr. T.M. Esat, Dr. D.A. Papanastassiou and Prof. G.J. Wasserburg, all of the California Institute of Technology, and by Prof. Donald E. Brownlee of the University of Washington. They used special instruments, originally developed to analyze Moon rocks and meteorites, that could handle, dissolve, and analyze the tiny particles without loss or contamination.

"This is a real breakthrough," said Dr. Bevan M. French, scientist for NASA's Planetary Materials program which supported the research. "There's a tremendous



Magnified about 15,000 times by a scanning electron microscope, this tiny particle of dust is believed to have been shed by a passing comet. The particle is one of the more common "fluffy" ones gathered. NASA photograph.

amount of this extraterrestrial dust around. About half a ton of it falls to Earth every day, and much of it may have come out of comets or new kinds of fragile meteorites that don't survive to reach the ground. We could get an enormous amount of new information out of this dust — but until now, we've never been able to collect these tiny particles free of contamination or to analyze them one at a time."

The dust particles were collected by aircraft flying high above the layer of terrestrial pollution, and they appear definitely extraterrestrial. Their chemical composition, measured with an electron microscope, is similar to that of known meteorites and not to terrestrial materials. More precise analyses of the elements magnesium and calcium, which were made in a special laboratory at the California Institute of Technology, suggest that small chemical anomalies are present in some of the particles. If these anomalies show up in more particles, it will indicate that the dust still contains evidence of nuclear reactions that occurred when the solar system was formed.

The successful analysis of possible "comet dust" comes at a time when NASA is actively planning a major mission to send an unmanned spacecraft to meet Halley's Comet when that brilliant visitor makes its next regular appearance in late 1985. The spacecraft would observe Halley's as the comet flashes by and then would rendezvous with a lesser-known comet called Tempel II. But no samples can be returned from either comet by this mission, and the dust analyses are even more important for the near future.

"Pieces of comets are probably raining down on our heads all the time, but we've never been able to analyze them before," says Dr. French. "With luck, we could find out a little about what a comet is made of before we ever see one close up." Brownlee and his associates collected the dust particles by attaching sticky plates to a NASA-operated U-2 aircraft. Carried to an altitude of 20 kilometers (65,000 feet), well above the contaminating terrestrial particles produced by volcanic eruptions and human activities, the plates trapped only extraterrestrial dust particles that had entered the Earth's atmosphere and were drifting downward.

Three different kinds of particles, most of them about 1/100 of a millimeter (1/2,500 of an inch) across, were discovered when the plates were carefully cleaned at the University of Washington. The most common particles are fluffy, and each one is made up of as many as a million separate grains of different minerals. A second type is also fluffy, but is made up of many tiny crystals of a single mineral. The chemistry of these two groups, measured with a scanning electron microscope, is like that of chondrites, one type of meteorite that falls to Earth, but the fluffiness of the particles indicates that they were never a part of any dense meteorite. A rarer type of dust particle also was found — tiny hard spheres formed by a melting event that took place either in the Earth's atmosphere or in outer space.

For more precise measurements of the elements magnesium and calcium, the samples were transferred to Esat and his associates in a special laboratory at the California Institute of Technology. This group hoped to detect small anomalies in the magnesium and calcium of the dust particles. Similar anomalies have been detected in the Allende meteorite that fell in Mexico in 1969. They apparently are caused by unique nuclear reactions that took place at the very beginning of the solar system or even before — possibly in a nearby supernova explosion that may have triggered the formation of our solar system.

Even for this experienced group which pioneered the work on lunar samples, the analysis of a single dust particle demanded a new level of technical skill. All the work was done in clean rooms and under special hoods so that no terrestrial dust could contaminate the analysis. Each tiny particle was carefully moved with mechanical micro-manipulators until it could be inserted into a tiny drop of acid placed on a thin wire made of high-temperature metal, rhenium. To make certain that the drop stuck to the wire, the scientists added a tiny bit of "orange juice" — a synthetic mixture of citric acid and sugar — to the drop. Then the wire was heated, the dust particle dissolved in the acid, the acid evaporated, and streams of atoms shot from the hot wire filament to be focused by a magnetic field and measured.

In most of the dust particles analyzed, the magnesium and calcium were "normal" — that is, like that found in earth rocks and most meteorites. In four particles, possible anomalies were observed in the magnesium. If these anomalies can be confirmed by analyzing more dust particles, it will show that some of this dust came from objects that go back to the beginning of the solar system — most likely comets, which have spent most of their lives deep-frozen beyond the edge of the solar system since they were formed 4.5 billion years ago.

Galileo Mission in Trouble

Project Galileo, NASA's most ambitious planetary mission since the Viking Mars landings, has run into trouble. After overcoming a gamut of previous obstacles, the Galileo mission to send an Orbiter and an atmospheric Probe to Jupiter is now being replanned in an attempt to cope with weight restrictions resulting from delays in the Space Shuttle. The original plan for Galileo was to deploy the Probe "piggybacked" on the Orbiter and launch the two-element spacecraft toward Jupiter using a solid-fuel Interim Upper Stage (IUS) booster from the payload bay of the Shuttle. The spacecraft would have used the gravity of Mars to achieve the velocity needed to reach Jupiter, an opportunity only available every two years when the red planet is properly aligned with Earth, as it will be in 1982 and 1984. Because snags in the development of the Shuttle main engines have delayed delivery of the improved "109 percent" engine, the extra thrust needed to lift the 4,600-pound Galileo and the IUS to carry it to Jupiter will not be available in time for the original 1982 launch date.

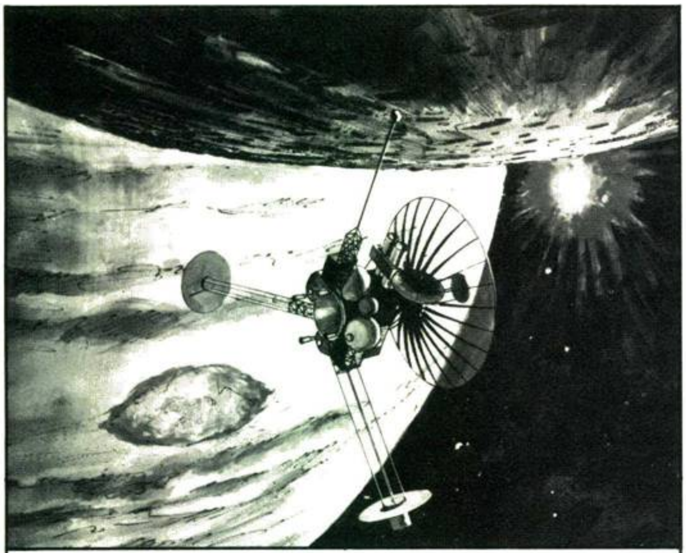
Since the advanced Shuttle appears indefinitely out of the picture, NASA planners can save the Galileo mission only by employing a different launch strategy to get the Probe, Orbiter, and IUS into Earth orbit. Using a very expensive "stretched" Titan-Centaur rocket, NASA could circumvent the need for the Shuttle launch and fly Galileo on the 1982 schedule. However, the combined cost of rebuilding Cape Canaveral launch facilities to accommodate the stretched Titan-Centaur and the price the Air Force wants for the big rocket would add $125 million to the original $285 million cost of Galileo.

A less expensive option would involve replacing the IUS originally slated to boost the Orbiter and Probe to Jupiter with a lighter, more efficient Centaur rocket launched from the Shuttle payload bay. While the Centaur would provide such excellent rocket performance that the mission would not require a Mars gravity assist and could be flown in 1983, its use would introduce an element of danger for the Shuttle astronauts.

Unlike the solid IUS, the Centaur burns liquid hydrogen and oxygen. While these volatile propellants are the source of its efficiency, they also pose a serious threat to the manned Shuttle in the event of an aborted launch. To make the Centaur safe enough to fly in the manned spacecraft, a system to purge the rocket's fuel into space in case of emergency would have to be developed at a cost of at least $100 million. In a telephone interview, Angelo Guastaferro, director of NASA's planetary programs, said that even though developing a purge system was "not a tough technical problem," it is possible that the troubled Space Shuttle program would not be able to have it ready for the 1984 launch opportunity.

Since weight is the problem, the Galileo mission could be flown without the Probe and become just an orbital mission. The Probe might then be launched by itself a year later if the Orbiter looked healthy enough to act as a relay for its radio transmissions.

The most attractive plan, and the one that NASA scientists now favor, is to split the mission and send the Probe 44 days after the Orbiter using a separate Shuttle launch. The IUS will



The Galileo Jupiter Orbiter takes a close look at one of the larger satellites of Jupiter in this NASA rendering of the proposed planetary mission. NASA artwork.

still be used as the booster for each spacecraft and 100% of the scientific objectives of the original mission preserved, but the double launch would be delayed to 1984. Instead of piggybacking on the Orbiter, the Probe will require its own carrier to drop it into the giant planet's atmosphere and act as a radio relay. The development of this carrier, two Shuttle launches, and the extra rocket for the Probe, will set the total cost of the delayed mission at a minimum of $350 million. Moreover, a 1984 launch will add two years of inflation to the price tag.

However, according to Guastaferro, delaying the mission does produce some benefits. One advantage that the dual mission has over the original plan is the ability to optimize the entry into the jovian system for each spacecraft. Originally, the trajectory of the Orbiter/Probe was a compromise which allowed the Orbiter to drop off the Probe but still fulfill its own objectives. Now, by relying on its own optimally targeted carrier that will flyby instead of having to brake and orbit, the Probe will be precisely placed and may be able to provide a few extra minutes of precious data to ground controllers. Another advantage of the dual spacecraft mission will be the ability of the Orbiter to transmit a good deal of Mars data during the gravity-assist maneuver in which it will streak within 272 kilometers of the planet's surface. In the original mission configuration, the instruments on the Orbiter would have been largely prevented from functioning at Mars by its passenger, the Probe.

One disadvantage of a double mission, however, is that such a mission could be subjected to "halving" by cost-conscious opponents of the space program in Congress. NASA officials don't like the prospect of being forced to choose between an Orbiter mission alone and a Probe mission alone.

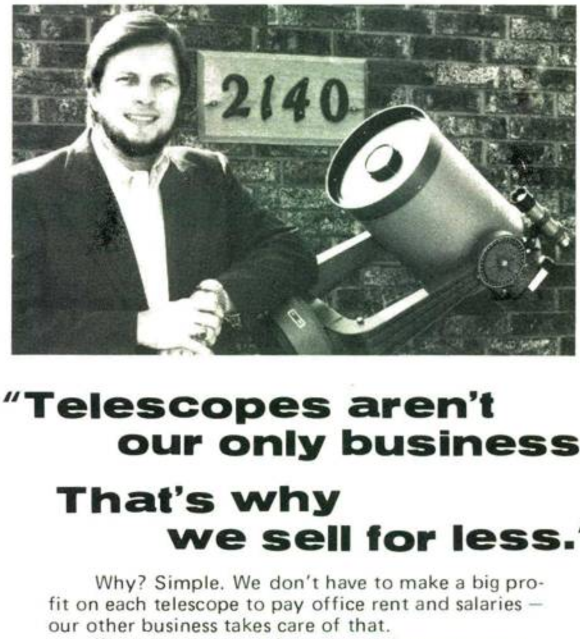
The Galileo mission has weathered tough times before, with the major area of concern being not Cape Canaveral or interplanetary space but Capitol Hill. Two years ago, the House Appropriations Committee voted to scrub the mission entirely. Fortunately, after bitter debate, the rest of the Congress, prompted by telegrams from scientists and petitions from Star Trek conventions, reinstated the project on the House floor. Senator William Proxmire, chairman of the Senate Appropriations Subcommittee with jurisdiction over space, tried again this year to kill Galileo but failed to win enough support in his own subcommittee.

In spite of delays and budgetary problems, the Galileo mission promises to achieve results so spectacular that they easily make it worth the wait and expense. By using the same techniques of gravity-assist with Jupiter's moons that it did with Mars, the dual-spin Orbiter will tour the jovian system, closely inspecting features unseen by any other spacecraft. According to a NASA source, "Some encounters will be so close — within one-tenth the radius of the satellites — that details as small as 30 to 50 meters will be recognizable. This is between 10 and 100 times more detail than that seen by the (two) Voyager spacecraft."

The Orbiter will circle Jupiter at least 11 times during a minimum of 20 months, encountering a Galilean satellite on each orbit. If the spacecraft survives longer than this period — a likely possibility considering the performance of other NASA vehicles — it could investigate the dawn regions of Jupiter, study the satellites further, or explore the general environment of Jupiter far above and below its equator.

The Galileo Probe, an impressive space vehicle in its own right, is expected to transmit data for about 60 minutes as it drifts through the jovian atmosphere. Revolving five times a minute on its parachute, it should survive to a depth of about 130 kilometers where weakening radio signals and intense heat will finally silence it. At this depth, the Probe will experience pressures equal to about 15 to 20 earth atmospheres. To conserve on weight, the spacecraft employs a vented probe design so that the pressure inside the Probe is always the same as the pressure outside. The contractor for the Probe is Hughes Aircraft, the company that built the magnificently successful probes for the Pioneer Venus Orbiter/Probe mission. If the Galileo Probe exceeds design specifications to even a fraction of the amount Pioneer Venus did, the mission should be a huge success.

Over 350 years ago, Galileo saw Jupiter's four largest satellites with a telescope of his own making. Prophesying the continued quest of the human spirit that carries on today with missions like Galileo, the German mathematician Johannes Kepler wrote the following words to his friend Galileo in April 1610: "There will certainly be no lack of human pioneers when we have mastered the art of flight...Let us create vessels and sails adjusted to the heavenly ether, and there will be plenty of people unafraid of the empty wastes. In the meantime, we shall prepare, for the brave sky-travelers, maps of the celestial bodies — I shall do it for the Moon, you, Galileo, for Jupiter."



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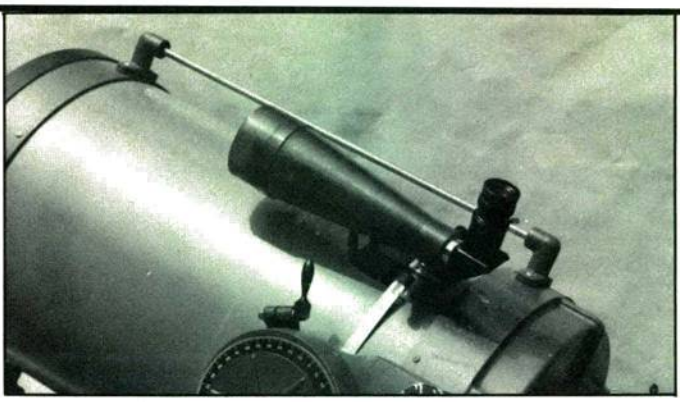

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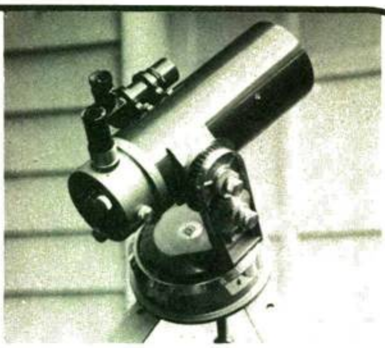

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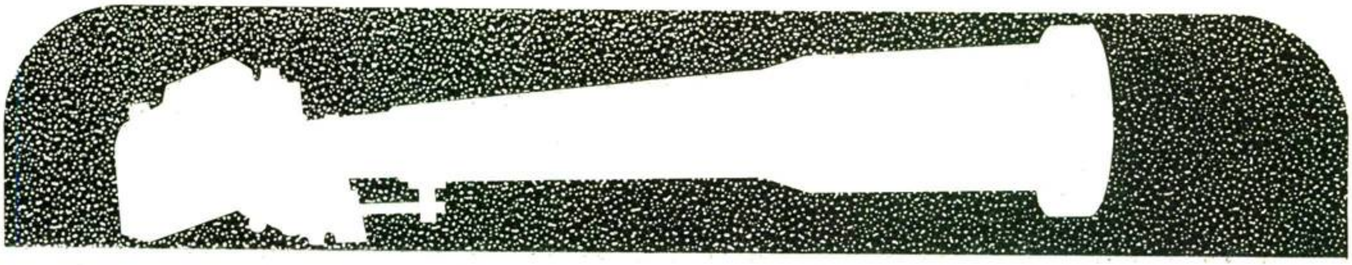


Tricolor Astrophotography

by Rev. Ronald E. Royer

One frustration of color deep-sky photography is that it doesn't lend itself to a high-quality large format image. With the modern high-speed color films available today, you can take excellent color deep-sky photographs with 35 mm cameras and lenses (usually telephotos) intended for daytime uses. For a bit more effort, you can put the 35 mm color films to use on Newtonian and Cassegrain reflectors, especially if you use a cold camera.

In both cases, however, the product of the area of the film and the angular coverage limits you. If you want to cover a lot of sky, you'll have to settle for a small image scale (and big enlargements with grainy images); if, on the other hand, you want a generous image scale, you have to settle for coverage of a field that grows smaller as the telescope becomes bigger.

"The Bigger the Better"

Large formats offer several ways to escape the small film limitations. First, they are the key to eliminating graininess. To obtain high-quality images, professional photographers have lugged around great big view cameras that thrive on a diet of large film, for their best work.

Second, large formats offer a larger field of view. Professional astronomers design their telescopes to take the largest photographic plates possible, because it doesn't take any longer to expose a big plate than it does a small one, but much more sky is recorded. Even relatively humble optics can cover a larger field than many astrophotographers realize: at f/10, a focal ratio now widely used for deep-sky photography, a Newtonian reflector can cover much of a 4" x 5" film.

One further stumbling block remains: many of the large format films available are very slow or, for one reason or another, unsuited for astrophotography. Thus deep-sky astrophotography has remained a field restricted to small format, high-speed films and fast optics.

Monopack — What's That?

But if we go back to the very early days of color photography, before modern "monopack" color films were invented, we find that color photography was being done. How? Photographers then used the "tricolor" technique, a method capable of producing quality images though it is no longer widely practiced today.

"Whoa," you're saying, "let's back up a moment: what are these 'modern monopack films' — I've never heard of them!" Monopack films are color films today — *they're all monopack*. The film consists of at least three different layers of emulsion, each sensitive to a different color of light, plus any number of auxiliary layers containing dye, etc. Monopack means that all these layers are combined into one ("mono-") package.

Before anybody got monopacks to work, a photographer would shoot three black and white pictures of the subject he wanted. Each picture would be shot through a separate color filter — one red, one green, and one blue. Since almost all the colors the human eye can see can be made by combining the light of these three primary colors, color photography is possible if you can break the image down into those three primaries, develop them as separate black and white pictures, then recombine them using the appropriate color filters or dyes.

Tricolor — First, Separate...

In tricolor photography, the photographer takes the image apart via his choice of filters and puts it back together again in the darkroom. The advantage the tricolor astrophotographer has is that he's not restricted to small films or the vagaries of monopacks made (basically) for snapshot photography. His films can be the ultra-sensitive, low reciprocity-failure Kodak spectroscopic films and plates.

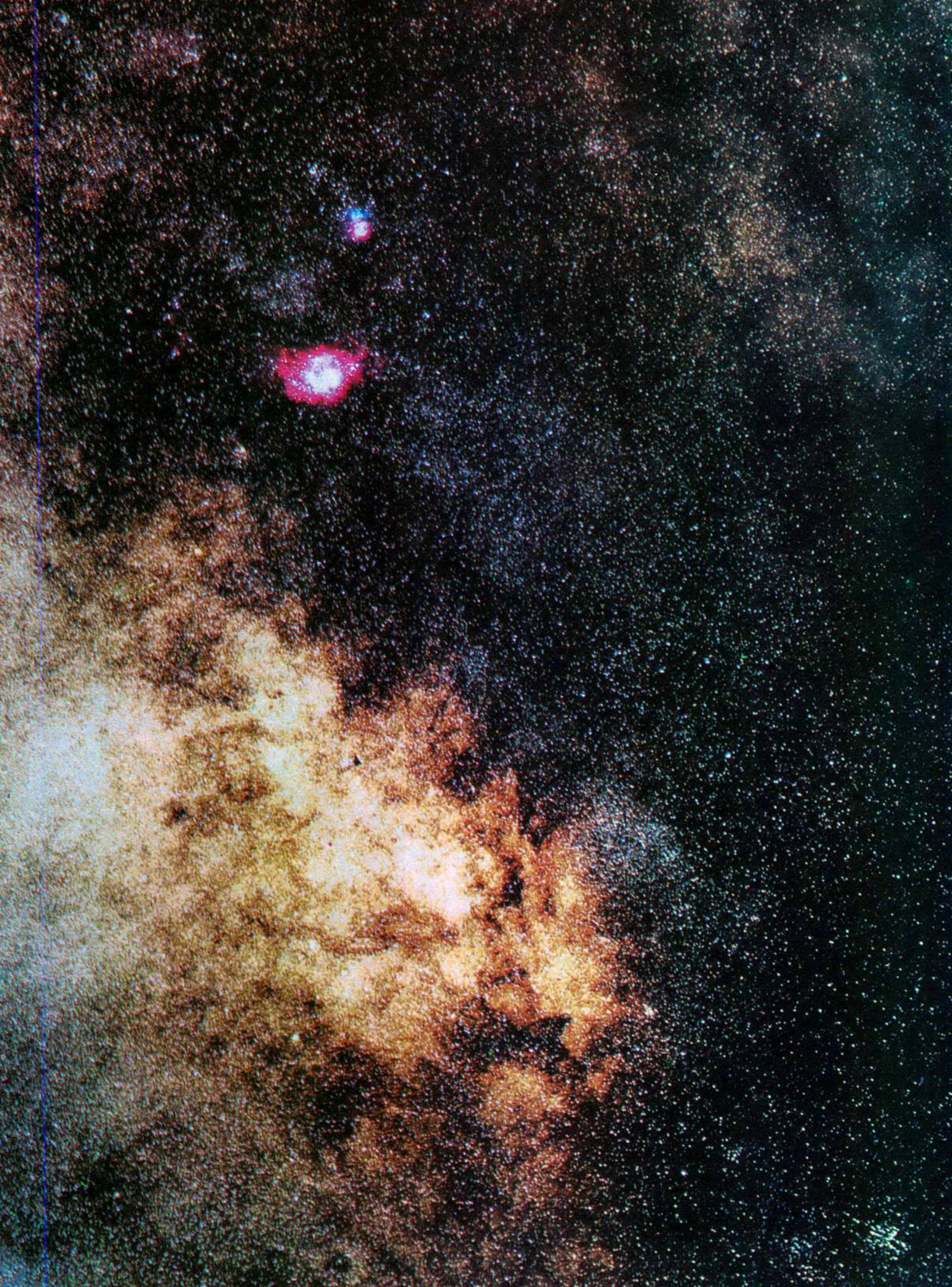
The pictures in this article were all taken using tricolor photography by the Rev. Ronald E. Royer of Lakewood, California. Most of his work is done with a 4-inch aperture, f/5 astrographic camera (see "Astrographic Cameras," Photography in Astronomy, November 1976) using 4"x5" glass plates. He built the lens himself during a course in optical fabrication at Citrus College in Azusa, California.

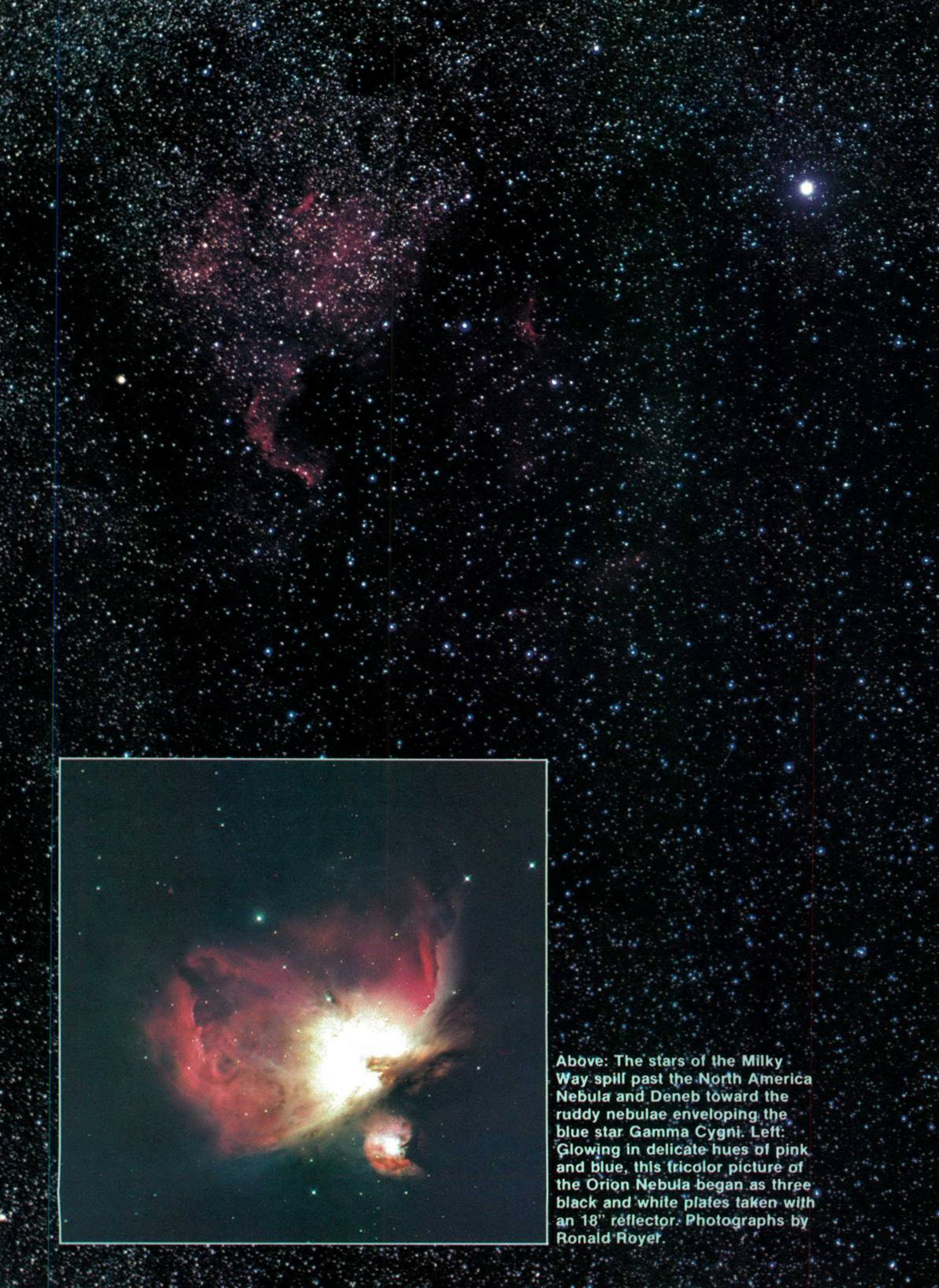
To make the blue light photograph, the blue and ultraviolet-sensitive spectroscopic emulsion IIa-O (pronounced two-ay-oh) is combined with a Wratten filter number 2A to cut out ultraviolet light. The "O" emulsion is not sensitive to green, yellow, orange, or red light at all. The blue plate normally receives a 50 minute exposure.

The green exposure is made on a type IIa-D plate. This plate is sensitive to ultraviolet, blue, green, and yellow light. A Wratten filter number 4 is used over the lens to block the ultraviolet and blue, so the plate records only green and yellow during a 50 minute exposure.

The red exposure is made on a type 098 plate, a new type that has finer grain and better sensitivity to the hydrogen-alpha line than the popular 103a-E. The 098 plates are sensitive to all the colors plus red, so a Wratten

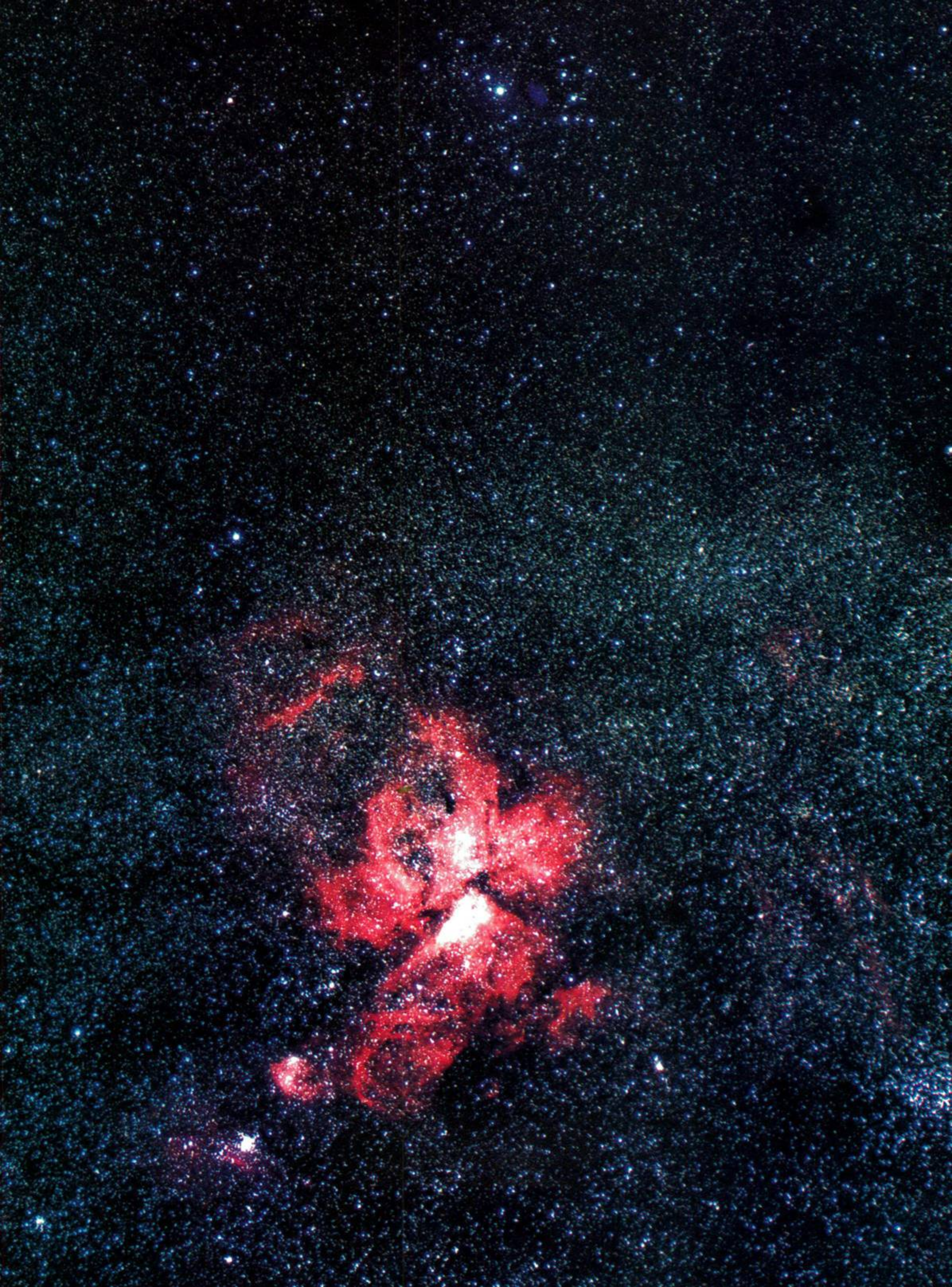
Small spots, streaks, and streamers of dark matter are silhouetted against the yellowish mass of the Sagittarius Star Cloud (lower left), and the Lagoon and Trifid Nebulae (top center) glow red in the light of excited hydrogen. To make this color image, three separate black and white negatives of the sky taken with a 4" f/5 astrograph were combined in the darkroom. Photograph by Ronald Royer.





Above: The stars of the Milky Way spill past the North America Nebula and Deneb toward the ruddy nebulae enveloping the blue star Gamma Cygni. Left: Glowing in delicate hues of pink and blue, this tricolor picture of the Orion Nebula began as three black and white plates taken with an 18" reflector. Photographs by Ronald Royer.

Its vivid blue gas tail streaming straight out, comet West was recorded on March 9, 1976 on two filtered black and white exposures shortly before morning twilight blotted the comet out. Photograph by Ronald Royer.



filter number 29 is used to cut out everything but the red light. The red exposure is usually 60 minutes.

These plates are standard Kodak stock items, but must be ordered through a professional dealer. A box of 36 plates costs upwards of $80 — they *are* expensive — and must be stored in a freezer or refrigerator until shortly before use. They are definitely not an item for a beginner.

The plates are developed in D-19 or Acufine developer with careful attention to even development. The best simple technique is to use an oversized tray and plenty of developer. The developed plates are then fully fixed and dried. A set of them is fascinating because they appear quite different: the blue plate tends to bring out clusters and groupings of stars, while the red plate shows diffuse nebulae especially well. The green plate tends to be dull, showing thousands of background stars.

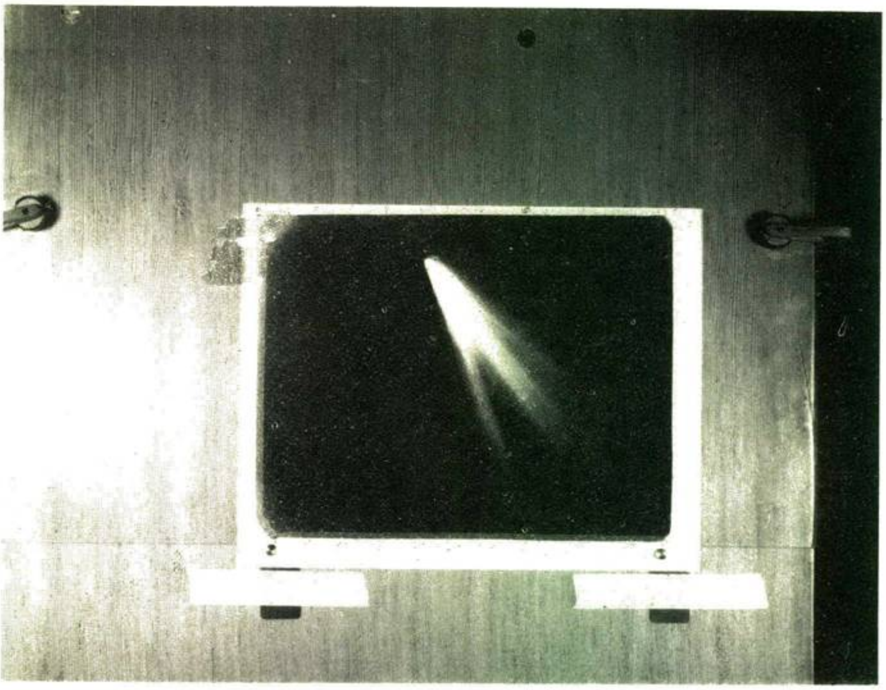
...Then Re-assemble

Putting the color back in is easier now than it was for the early photographers because we now have fine monopack color films available for forming the final image. The basic idea is to make three precisely matched and registered black and white enlarged positives of the three sky pictures, then rephotograph them sequentially through appropriate color filters onto a modern monopack film.

To hold the images in precise alignment, you'll use a two-hole paper punch and a set of register pins. Begin by placing the first negative in the enlarger and composing and focusing your picture. Punch a sheet of photopaper (Ilfo-Speed #5 works very well), place it on the register pins, cover with a sheet of ⅛" window glass to keep it flat, then expose, develop, fix, wash, and dry it. You may have to make several to get a background sky tone that's not perfectly black, but shows a little gray. Mark which color you've printed so you don't get the prints mixed up.

Now you're ready to make the second print. Place the first print back on the register pins, insert the second negative into the enlarger, and line up the images precisely. You may have to use a magnifier to check that tiny star images are aligned everywhere. Make the second print exactly as you did the first, making several if necessary to precisely match the background sky tone of the first.

The Eta Carinae Nebula ranks high among magnificent celestial objects for photography in the southern sky. The tricolor method captures not only the brilliant colors of the nebula itself, but also preserves the more subtle colors of stars, star clusters, and small nebulous regions. Photograph by Ronald Royer.



The pictures in this article were color composited on a copy board (simply a sheet of ¾" plywood) equipped with register pins. Each of three black and white originals was attached to the pins, covered with a sheet of ⅛" window glass, and copied through an appropriate filter onto color film. The picture shown on the board is one of Comet West—note that one of the black and whites was not correctly registered.

After you've made all three prints, go back and check the registration of the star images on the dried prints once more. If it's not perfect, the stars will come out looking like little rainbows in the final image.

You're now ready to re-assemble the celestial colors you took apart. You're going to rephotograph each black and white print through a color filter onto color film. It's best to use the same f/stop throughout the copying process, and of course you can't kick the camera between exposures!

Copy the blue print through a Wratten #99 filter, the green plate through a #98, and the red through a #25. These filters have very deep, strong colors. Place each print on the copyboard (this can double as your enlarger easel and you'll be assured of easier registration, too), cover with the ⅛" window glass, and make an exposure. With the camera stop set at f/11, under two tungsten photofloods, you might start experimenting with a ½-second blue exposure, ¼-second green, and 1/15-second red.

You can make the final color images on any film size you like, from 35 mm on up; those in this article were copied on 4" x 5" format film.

Color Control

You can control the color balance of your final image by adjusting the exposure times. If the picture shows an excess of one color, reduce the exposure from that tricolor image. You have virtually complete control over the final color balance and density: you can achieve deep, rich colors with a relatively dark print, or you can show fields chock-full of stars and nebulosity with a relatively light print. If possible, the copying setup should not be disturbed between uses or you'll spend too much time getting everything recalibrated every time you work.

What colors *should* sky objects and the background sky appear? The overexposed images of stars will show up as pure white. The color of the night sky is constantly changing, so it isn't a reliable guide; generally, however, it isn't the deep blue that most people think it is. It tends toward a greyish-green or cool grey somewhat like an overcast daytime sky, but very small amounts of light pollution can give a vivid green or sickly yellow cast to the entire sky. Globular clusters are generally pale yellow, and therefore of some value as points of color reference; nebulae are usually too red or magenta to be useful as a guide. The best-looking prints are those with a neutral or somewhat blue background sky. Even though that sky color is probably not often correct, the small color adjustments necessary to achieve it usually do not affect the color of the celestial objects appreciably.

Father Ronald Royer is a parish priest at the St. Pancratius Rectory in Lakewood, California. He has specialized in fine astrophotography using a precision 4" f/5 astrographic lens he made himself.

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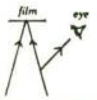

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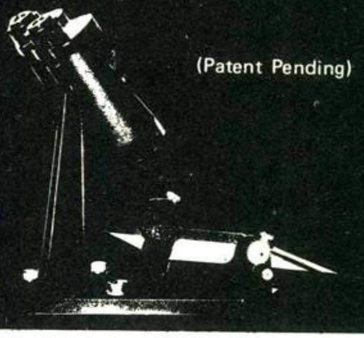

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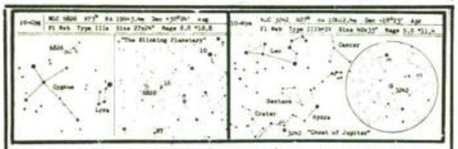

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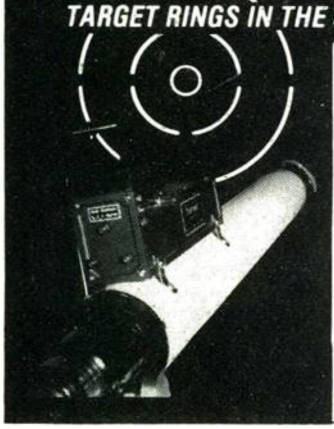

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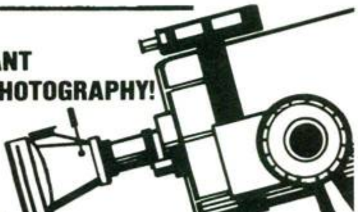

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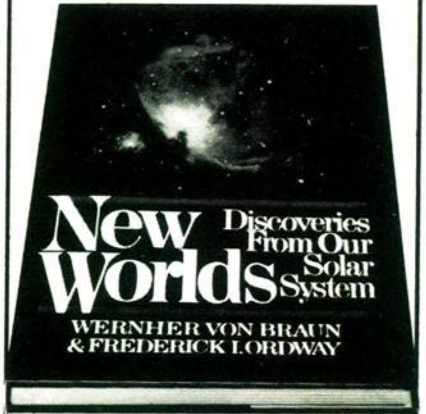

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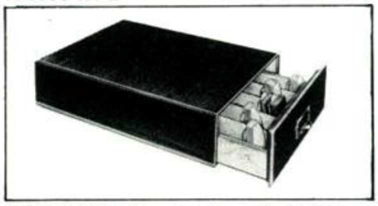

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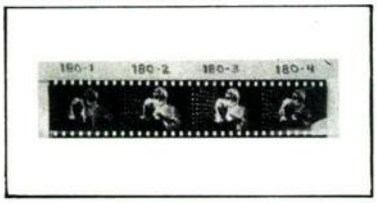

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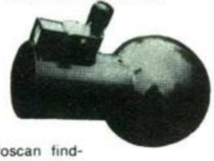

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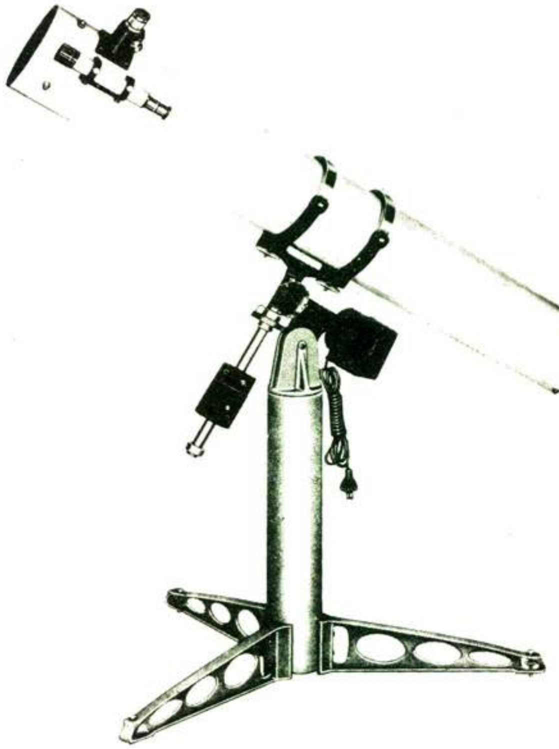

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December

by
Dewey Schwartzenburg
and
James Mullaney

December brings us once again to winter and the end of another year, dramatically marked by the rising of Orion, the mighty hunter of winter, early in the evening. His form bisected by the celestial equator, the constellation Orion is certainly the most familiar of the "winter constellations." Therefore it may come as something of a surprise to discover that Orion has not always been a "winter" hunter, and in fact the days will come when he will be found, low in the sky, on *summer* evenings instead.

To understand why, we must first answer a seemingly unrelated question: How long is a year? That question is not as easy to answer as you might think. In the first place, it's vague, since there are actually several different kinds of "years," depending on how you define them. Normally we think of a "year" as the time it takes the Earth to complete one revolution around the Sun, returning to the exact point in its orbit where it was one "year" before. This period is known to astronomers as the *sidereal year*, but in fact the sidereal year is not the same length of time our present calendar considers one year.

Our calendar year is what is called a *tropical* (or solar) *year*, and it is about 20½ minutes shorter than the sidereal year. Thus, in one tropical year the Earth (as seen from the stars) has actually not quite completed one full orbit, so January 1 of each successive year finds the Earth a little farther behind the point where it was on the previous January 1.

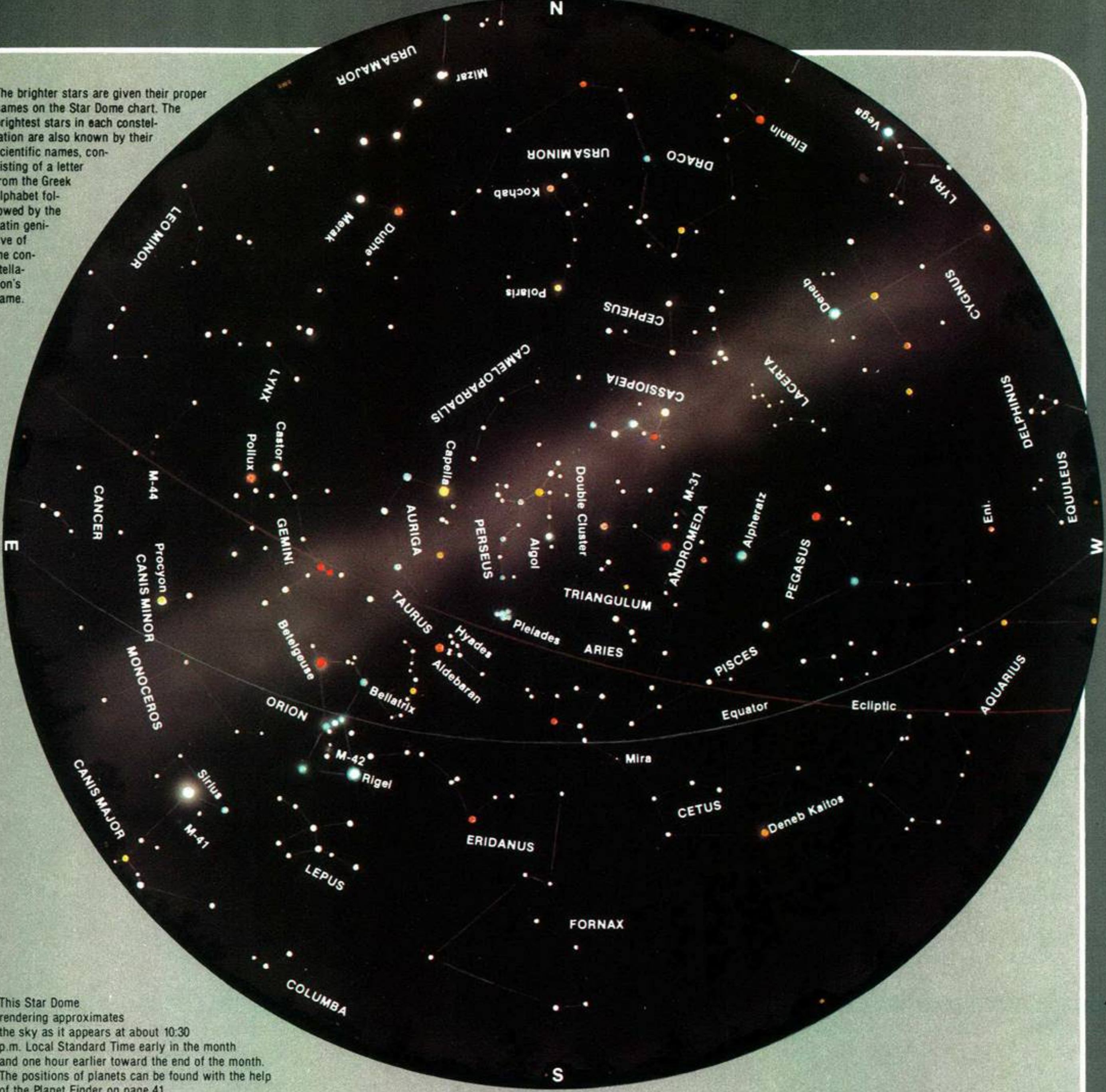
The tropical year is the length of time between two successive *vernal equinoxes* (when the Sun crosses the celestial equator from south to north). Our calendar is based on this, which means that the vernal equinox will always occur on or about March 21 every year. Therefore January and February will always be winter months (in the northern hemisphere) and July and August, summer. We use the tropical year as the basis of our calendar for just that reason: to keep the seasons from wandering around through the months.

If we used the sidereal year instead, the seasons would move, because the vernal equinox isn't a fixed point on the sky. It has long been known that the point at which the Sun crosses the celestial equator moves around the sky, a phenomenon called the *precession of the equinoxes* (or simply, precession). This happens because the axis of the Earth's rotation is tilted 23½° from the poles of its orbit (called the ecliptic poles), and the forces of solar and lunar gravitation cause the Earth's axis to circle slowly around the ecliptic poles. This is indeed a very slow process, taking 25,780 years to complete. Thus the point of the vernal equinox where the Sun crosses the celestial equator from south to north will travel completely around the sky in nearly 26,000 years.

Of course, the apparent path of the Sun against the background stars (the ecliptic) remains fixed the entire time, so that the thirteen constellations of the Zodiac will never change. Because of precession, however, the Sun will not always be in the same spot on a particular calendar date. For example, the vernal equinox is also known as "the first point of Aries" — a puzzling designation since it happens to be in the constellation Pisces! But it was not always so, and until about the year 400 A.D., the vernal equinox *was* indeed in the constellation Aries. A few hundred years from now, it will move into the constellation Aquarius (which lies behind the somewhat premature astrological claim that we are now living in the "dawn of the age of Aquarius").

The apparent movement of the vernal equinox around the celestial equator means that all the constellations slowly shift relative to the calendar date. Orion is now moving in the direction of autumn, and in about 13,000 years it will once again be seen in the sky on summer evenings. Other interesting changes also take place, for in addition to the seasonal shift, the tilt of the Earth's poles will cause the celestial equator to move relative to the ecliptic. This means, for example, that while Orion now sits astride the

The brighter stars are given their proper names on the Star Dome chart. The brightest stars in each constellation are also known by their scientific names, consisting of a letter from the Greek alphabet followed by the Latin genitive of the constellation's name.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CAMELOPARDALIS
CASSIOPEIA
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LYNX
DELPHINUS
Castor
Pollux
Capella
Double Cluster
M-31
EQUULEUS
M-44
CANCER
AURIGA
PERSEUS
Algol
ANDROMEDA
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Enf.
E
Procyon
CANIS MINOR
GEMINI
PEGASUS
W
TRIANGULUM
TAURUS
Pleiades
Hyades
ARIES
Betelgeuse
Aldebaran
PISCES
MONOCEROS
Bellatrix
AQUARIUS
ORION
Equator
Ecliptic
M-42
Mira
CANIS MAJOR
Sirius
Rigel
CETUS
Deneb Kaitos
M-41
ERIDANUS
LEPUS
FORNAX
COLUMBA
S

This Star Dome rendering approximates the sky as it appears at about 10:30 p.m. Local Standard Time early in the month and one hour earlier toward the end of the month. The positions of planets can be found with the help of the Planet Finder on page 41.

equator, in 13,000 years it will be found far to the south. In fact, the "belt" of Orion, now nearly on the equator, will lie at a declination of about -47°, so far south that the whole constellation will never rise above the horizon in the north temperate latitudes.

At the same time, though, when Vega will be our "north star," the rich Milky Way regions of Sagittarius and Scorpius will ride high in the sky well above the celestial equator — but in January and February instead of July and August. Perhaps the longer nights of winter will make up in part for the discomfort of the cold. And a little later in those winter nights of 15,000 A.D., North American observers will be treated to the sight of the magnificent constellation Crux (the Southern Cross) rising above the southern horizon. Ursa Major's paws will almost touch the equator, and Sirius the dog star will no longer be visible from the United States. Sky watchers in times to come will be presented with a very different sky indeed.

In fact, the sky will be even more different than the above suggests. The so-called "fixed stars" aren't actually fixed, of course, and as we now know, each drifts through space with its own "proper motion." The motion of the individual stars, however, is so slow that it takes thousands of years to produce a noticeable change in the familiar constellation patterns. But the fullness of 13,000 years will undoubtedly result in significant alteration in our present asterisms, so that, for example, the Big Dipper will no longer be recognizable as such. The "pointer" stars Merak and Dubhe will no longer point to Polaris, which in any case will no longer be the north star either.

Close-Up

Aries/Triangulum

This month's region consists of two adjoining celestial precincts — the zodiacal constellation Aries (the ram) and its tiny neighbor Triangulum (the

triangle). The former ranks 39th in size among the 88 recognized star groupings, while the latter comes in at 78th. You'll find the brighter units of both arranged in distinct triangular patterns just south of the well-known triple star Gamma Andromedae.

"Three stars near together mark it to the naked eye, but it reaches some way farther east into a dull region" was Webb's account of Aries, while for Triangulum he wrote: "An ancient constellation, including several good objects." In the former group, Barns considered the stars Alpha (α), Beta (β), and Gamma (γ) "quite the most engaging portion of an otherwise indifferent constellation" and for the latter noted: "A limited but well-placed asterism, with at least one feature of superlative interest." The object he referred to is the great galaxy M-33, which we'll get to later.

In his account of Aries, Olcott brought to light a curious and little-known fact, namely "the pair of stars, Beta and Gamma Arietis, are one instance out of many where conspicuous stars form pairs, the brighter of the two lying generally to the east." The heavens abound with such oddities and coincidences — another is that many of the best double stars carry the Greek letter designation Gamma (γ) in their respective constellations, those in Aries, Andromeda, Leo, and Virgo being examples.

As the table of selected objects indicates, nearly all of this dual region's attractions are stellar in nature. Sweeping is poor here, and there are no clusters or nebulae of note and but one outstanding galaxy. Both Aries and Triangulum appear as triangles in the sky and — seemingly in keeping with this triad theme — there are three real showpieces here for the telescope, which we shall now examine in detail.

Gamma (γ) Arietis

The finest deep-sky object in Aries is the stunning silvery double star Gamma. Lowermost in the sky and faintest of the constellation's three brightest units, this duo is readily identified and is a superb sight in even the smallest of telescopes.

Gamma consists of two perfectly matched 4.8 magnitude suns separated by about 8 seconds of arc in position

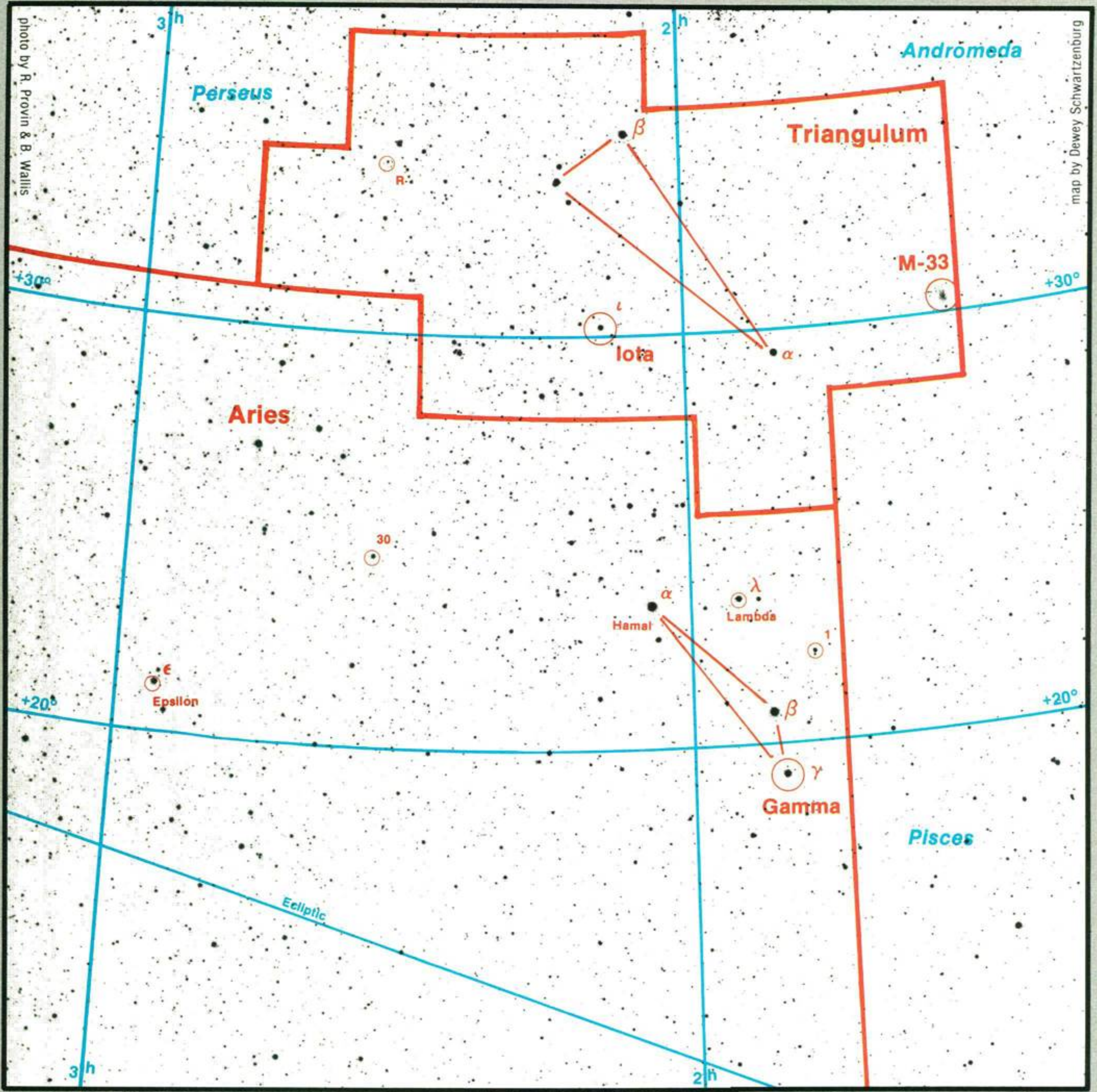


photo by R. Provin & B. Wallis

map by Dewey Schwartzenburg

angle 360° (or exactly north-south on the sky). A 2-inch glass splits the pair nicely at just 30 power, while the same instrument at 100 diameters or more reveals the spurious diffraction disks and rings on all but the most turbulent nights. As telescopic aperture increases, this duo becomes ever more radiant. However, keep the magnification as low as possible so the components are not unduly spread apart, negating the effect.

One of the very first double stars to be found with the telescope, Gamma's duplicity was accidentally discovered by the English astronomer Hooke in 1664 while following a comet. As he related it: "I took notice that it consisted of two small stars very near together; a like instance to which I have not else met with in all the heaven."

Both components of Gamma are hot A0 type suns and appear white or blue-white to most observers. Smyth noted the tints as "light white and pale grey or faint blue" and Olcott similarly found them "white and pale grey." Webb gave the colors as "very white and yellowish-white," calling this a "good object for small telescopes." Muirden considered this object "one of the finest pairs in the sky; both yellow; easy with low power." Still other accounts are those by Norton ("beautiful fixed pair"), Brown ("matching pair of white stars"), and Robert Burnham, Jr. ("fine pair, both white").

Gamma Arietis appears on most lists of deep-sky showpieces including Flammarion's lineup of the 25 best pairs and Colas' table of finest white doubles. One exception is Pickering, who surprisingly gave this duo only "runner-up" status to his roster of the sky's 60 finest objects. Do you agree with his assessment based on your own eyepiece impressions?

Some observers have reported a slight difference in brightness of Gamma's components amounting to a few tenths of a magnitude. Do they look perfectly equal to you? In making your observations, check the images both in and out of focus, and also with the line joining the stars both vertical and horizontal in the telescope (by turning your head or rotating the star diagonal if your instrument has one). Do these variations produce the same or different results?

Although little change in the relative position of Gamma's components has been found in more than three centuries of observation, the pair is drifting through space together and no doubt forms a long-period binary system in very slow orbital motion about each other. And the stars certainly seem associated at the eyepiece, apart from any physical information. The separation had decreased slightly from about 9 seconds in the early 1800s to its present value of 7.8 seconds. Lying some 160 light-years from us, these stellar twins are waiting to greet you the next clear night.

Iota (ι) Trianguli

Moving southward now into Triangulum, we find the second in our trio of December showpieces. This is the lovely double star Iota (ι) Trianguli (also designated by its Flamsteed number, 6, on some lists and atlases), offering an obvious and pleasing color contrast for the telescopist. Faintly visible to the unaided eye as a 5th magnitude star, it forms a triangle with Gamma and Alpha Trianguli — look for it south of the former and east of the latter. A line drawn from Gamma Andromedae southward through Beta Trianguli also points directly at its position.

Iota is a striking combination of 5.4 magnitude gold and 7.0 magnitude blue suns spaced just under 4 seconds apart near position angle 72°. A 3 or 4-inch glass resolves the pair neatly at about 75 power, and the view becomes more striking as aperture and (in this case) magnification increase. A 6 or 8-inch scope at 100 to 150 diameters gives a truly commanding view of these tinted jewels and they are an ideal target for public viewing with large-size instruments.

The difference in spectral type of the primary and companion — G5 and F6, respectively — causes the color difference mentioned in most descriptions of this object. Burnham described Iota as "an attractive double star with a noticeable color contrast, probably first observed by (Sir William) Herschel in 1781." Colas included the pair in his list of the finest colored doubles, giving the tints as "gold-yellow and bluish-green." Smyth found them "topaz yellow and green," and called this object "exquisite." Webb, Norton, Olcott, and Muirden are among those who simply noted the colors as yellow and blue. One of the few exceptions to the foregoing impressions is that by Hartung, whose description reads: "bright golden yellow pair." Another is that by Barns who gave the hues as "sapphire and gold" — apparently in reverse order from the method usually followed (primary first, companion second). What shades do you find here in your telescope?

As in the case of our first offering, the visual members of Iota form a very long period binary showing little change in position angle and separation over the years. But here, both suns are also close unresolved spectroscopic binaries forming a complex quadruple star system. The period of the A pair is 15 days and the B pair 2 days, the foursome together lying at a distance of about 200 light-years.

Iota Trianguli seems little known or observed by modern stargazers, perhaps being overshadowed by its brighter and more spectacular neighbor Gamma Andromedae. Nestled beneath the heavenly triangle, this neglected duo awaits your inspection the next clear night. Give it a look — as those who have seen it will tell you, you're sure to like it.

Selected Objects — Aries/Triangulum

Object	Type	Mag.	Size/Sep. Per.	R.A. (1950)	Dec.
*M-33	§S	6.0	65′x35′	01^h31^m	+30°24′
1 Ari	★^{2}	6.3,7.4	3″	01^h47^m	+22°02′
*Gamma (γ) Ari	★^{2}	4.8,4.8	8″	01^h51^m	+19°03′
Lambda (λ) Ari	★^{2}	4.8,7.4	37″	01^h55^m	+23°21′
*Iota (ι) Tri	★^{2}	5.4,7.0	4″	02^h10^m	+30°04′
R Tri	m★	5.4-12.5	266^d	02^h34^m	+34°03′
30 Ari	★^{2}	6.6,7.4	39″	02^h34^m	+24°26′
Epsilon (ϵ) Ari	★^{2}	5.2,5.6	1.5″	02^h56^m	+21°08′

*Detailed in Close-Up

★ *Star*
★^{1} *Bright Star*
★^{2} *Double Star*
★^{3} *Triple Star*
m★ *Regular Variable*
n★ *Irregular Variable*
ĸ★ *Eclipsing Variable*
○ *Open Cluster*
● *Globular Cluster*
■ *Planetary Nebula*
□ *Bright Diffuse Nebula*
§0 *Elliptical Galaxy*
§S *Spiral Galaxy*
§/ *Barred Spiral Galaxy*
§# *Peculiar/Irregular Galaxy*

M-33

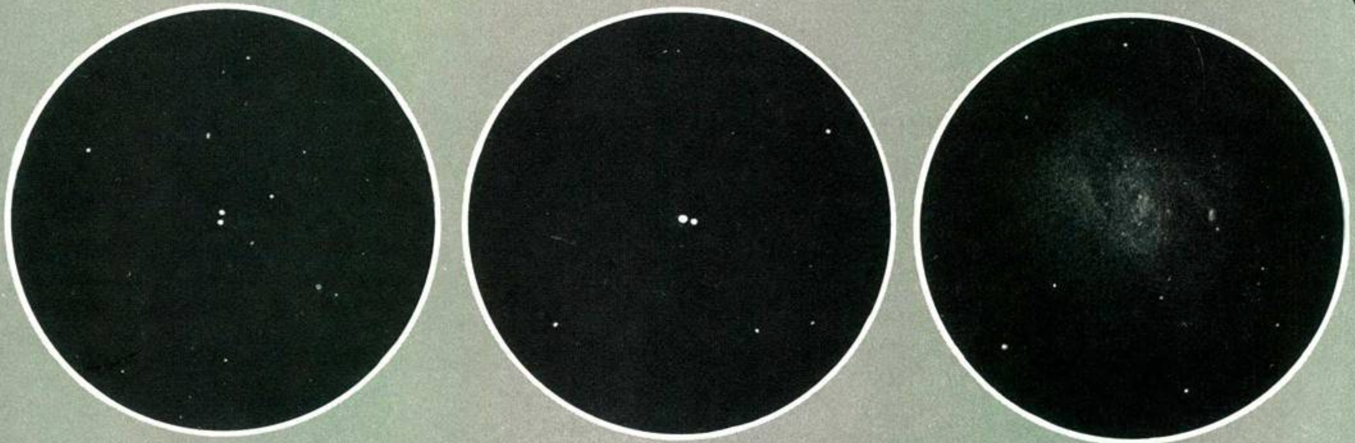
Jumping now from a few hundred light-years to a distance of some 2,400,000 light-years, our final showpiece this month is the nearest and apparently largest of the spiral galaxies after M-31 in Andromeda. This is M-33, the great Pinwheel Galaxy of Triangulum. You'll find it lurking roughly one-third the way from Alpha Trianguli to Beta Andromedae. A line extended from Mu (μ) Andromedae through the latter star points directly to its place in the sky.

This huge Sc-type spiral is a member of the Local Group of nearby galaxies — a clan that includes (among others) M-31 and its companions, the two Magellanic Clouds and, of course, our own Milky Way system. Measuring over half a degree across visually (or larger than the apparent size of the Moon), it spreads fully 65 by 35 minutes on time-exposure photos. Its magnitude is variously given as anywhere from 7.0 to 5.3, the value of 6.0 in our table being a compromise based on the fact that this object has been reported with the naked eye under dark-sky conditions. However, M-33 looks much fainter at the eyepiece than these figures lead you to believe, since they represent its *integrated* (or total) light. The galaxy is so spread out that its per-unit-area, or surface brightness, is rather low, and this is what counts at the eyepiece.

M-33 is easily passed over in a telescope, the more so as magnification increases and field of view decreases. Spotting it first in a pair of binoculars and then going to the finder seems to help. Many observers find the most direct way to pick it up is very slow sweeping with the telescope directly, using a low-power, wide field (at least 1°) eyepiece.

Low magnification is indeed one important key to quick identification of M-33. About 25 to 30 power works well on a 2 or 3-inch glass, as does 30 to 60 power on 6 to 10-inch instruments. A 4 or 6-inch richest field telescope (RFT) gives excellent results at just 15 to 25 diameters.

Another key here — indeed, a critical one — is the sky condition. Dark (moonless) transparent nights are essential for success, especially if you are a beginning observer. Viewing the spiral structure present also requires good seeing (image steadiness), since turbulence blends the arms together into an amorphous glow. Larger amateur instruments make them more definite and also reveal many bright knots within the arms themselves. On the other hand,



Left: Gamma (γ) Arietis appears as a striking pair of identical stars aligned exactly north-south in the sky. Center: Separated by four seconds of arc, the two components of Iota (ι) Trianguli offer a pleasing color contrast. Right: Seen nearly face-on and huge in extent, the magnificent spiral galaxy M-33 in Triangulum is difficult to locate because of its low surface brightness. Drawings by James Mullaney.

their reduced fields of view make finding the galaxy more difficult in the first place.

Now let's hear what various observers over the years have said about the appearance of this vast stellar pinwheel. One of the most complete of the classic descriptions of this object is that of Webb as he viewed it through his 3.7-inch refractor: "Very large, faint, ill-defined; visible from its great size in finder, a very curious object, only fit for low powers, being actually imperceptible, from want of contrast, with my 144 (power). Resolved by William Herschel into stars, 'the smallest points imaginable.' The Earl of Rosse, who only saw it full of knots, found the same spiral arrangement which prevails so wonderfully in many nebulae: two similar curves, like an S, cross in the centre. Closely north following is HIII-150, a small, bright round nebulosity."

This latter object is NGC-604 and is actually a part of M-33 itself, being one of the bright emission nebulae in its graceful spiral arms. It lies about 10 minutes of arc from the nucleus on the northeast edge of the visual image, and is obvious on a good night in 6-inch and larger apertures. Some observers find it elongated rather than round in shape; in either case, it resembles the image of a field star. As its early designation indicates, it was found by William Herschel. (For some reason, M-33 itself also carries a Herschel number — HV-17 — although it was recorded by Messier who described it as a "whitish light of almost even brightness.")

Herschel found a "mottled aspect" to M-33's light and with his great reflectors resolved it into the pinpoints described by Webb in his account. In a good 8-inch telescope at 70 to 90 power, the central region of the galaxy does indeed seem "grainy" in texture, giving the impression of countless stars on the verge of resolution.

The *NGC* calls M-33 "remarkable" (which it surely is) and describes it as "extremely bright, extremely large, round, very gradually brighter in the middle to a nucleus." Burnham called it "a challenging object for the small telescope."

Muirden's account of M-33 reads: "This is a notoriously difficult object, for it is both large and faint, and too high a magnification renders it invisible from lack of contrast. A good finder will show it best, and under good conditions it can be glimpsed with the naked eye."

Likewise, Holyoke called this object "a troublemaker for beginners who have a hard time seeing it in a telescope. The secret: Use a low power and get the eyes adapted to the darkness. This galaxy has a low surface brightness and is very large. It is therefore an excellent practice object...Once found it isn't difficult."

And again, Brown found M-33 to be "marvelously photogenic but hardly more than a grey cloud in a small telescope — you can go right over it without ever knowing you were there." He goes on to state that this object requires at least 10 inches of aperture — an opinion that few observers will share.

M-33 appears on some but not all deep-sky showpiece rosters. For example, Flammarion included it in his lineup of the 21 brightest galaxies, but Pickering relegated this object to his "reject" list. Bernhard, Bennett, and Rice placed it in their classic compilation with the comment: "Very large but not clearly defined, and needing low telescopic power with large enough aperture...Full of detail in spiral structure, with nebulous condensations." Likewise, Norton found it a "very large, faint, ill-defined nebula: central portions the brightest; irregular nodosities give it a curdled appearance. Use very low power on a dark, clear night."

The late John Mallas considered M-33 easy in 7 x 50 mm binoculars but very faint and difficult in his 4-inch refractor. In the latter instrument he found this object "consists of a faint central region surrounded by fainter, soft grey patches, which are difficult to distinguish from nearby stars." He also pointed out the following curious feature, which you might like to confirm for yourself on a clear turbulent night: "In field glasses or small short-focus instruments...M-33 and the surrounding stars present a three-dimensional effect. It occurs when the air is not steady."

Perhaps the finest and most enthusiastic of the classic descriptions of M-33 is that by Barns, who saw it in his 10-inch reflector from the clear skies of California half a century ago as "over ½° in extent, with crosses, rifts and nebulous condensations in a sea of glory!"

As with many other wonders of the nighttime sky, M-33 takes some getting used to and seems to grow on you the more you view it. This colossal star city in the night is indeed a showpiece among galaxies, but a combination of proper instrumentation, observing experience, and good sky conditions is necessary to appreciate its true grandeur. Only then, as Olcott so eloquently expressed it, will you "behold a vision of loveliness that is exalting; then, perhaps, for the first time you will glimpse the full meaning of the word 'glory.' "

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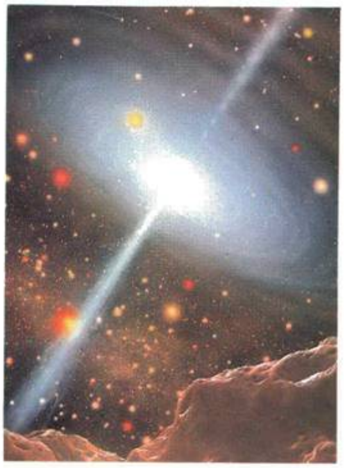

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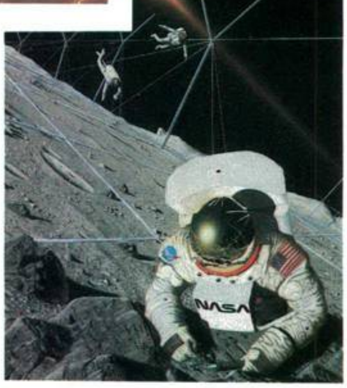

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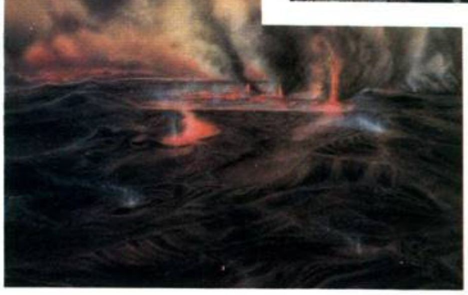

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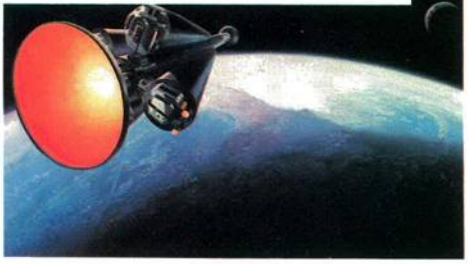

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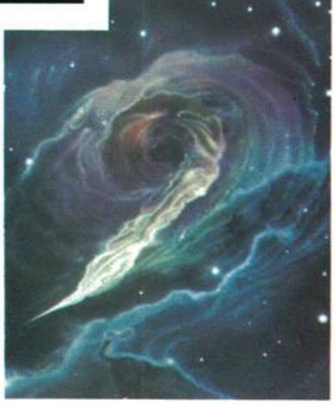

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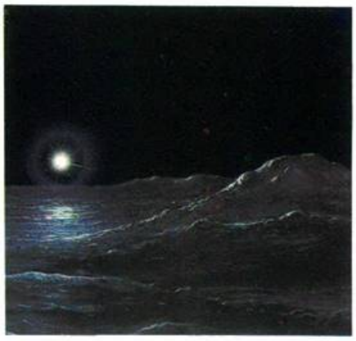

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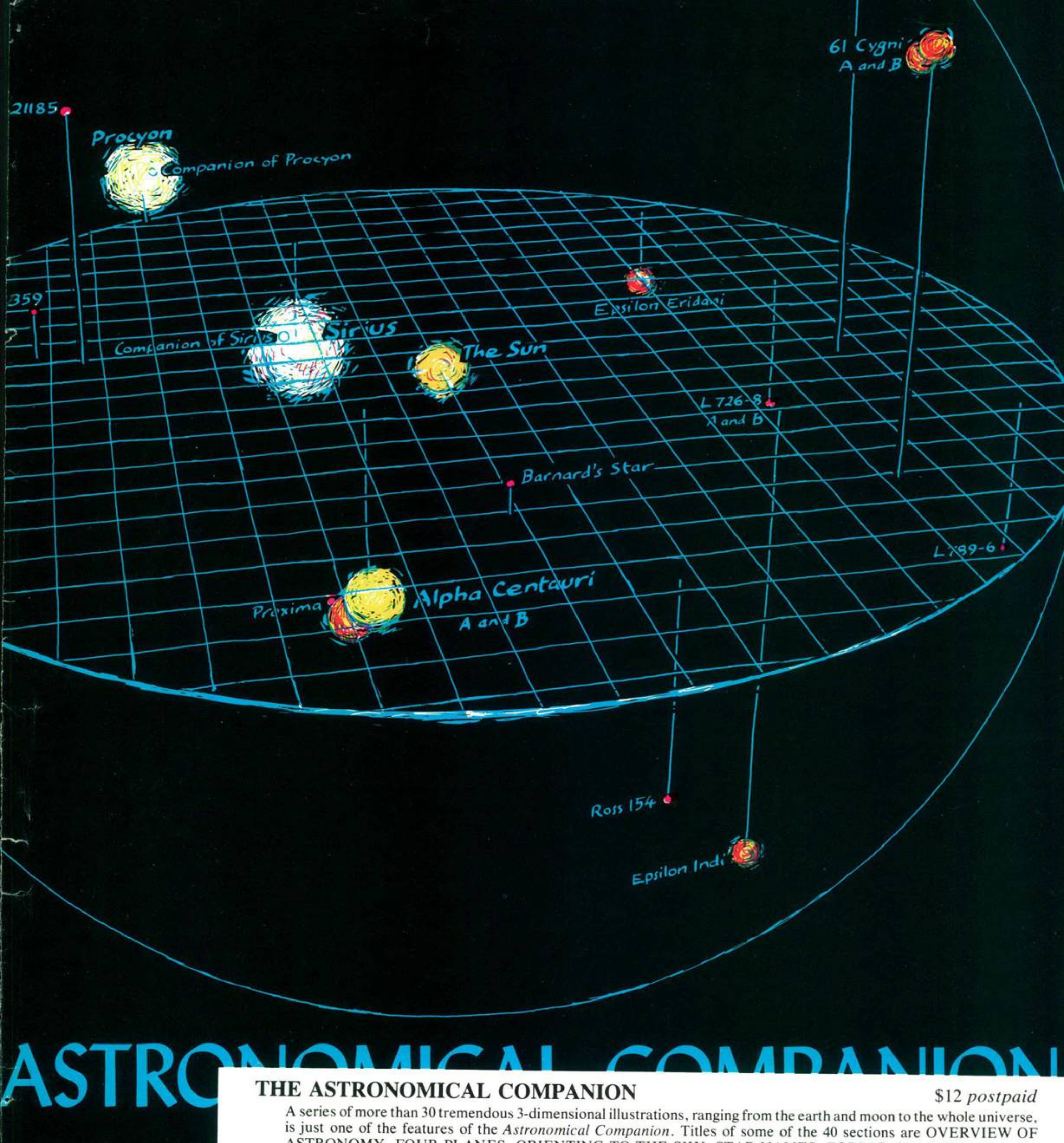
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